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Advancing Automation and Robotics Technology for the Space Station *Freedom* and for the U.S. Economy

NASA Advanced Technology Advisory Committee

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Progress Report 16
September 17, 1992 through March 16, 1993
Submitted to the Congress of the United States
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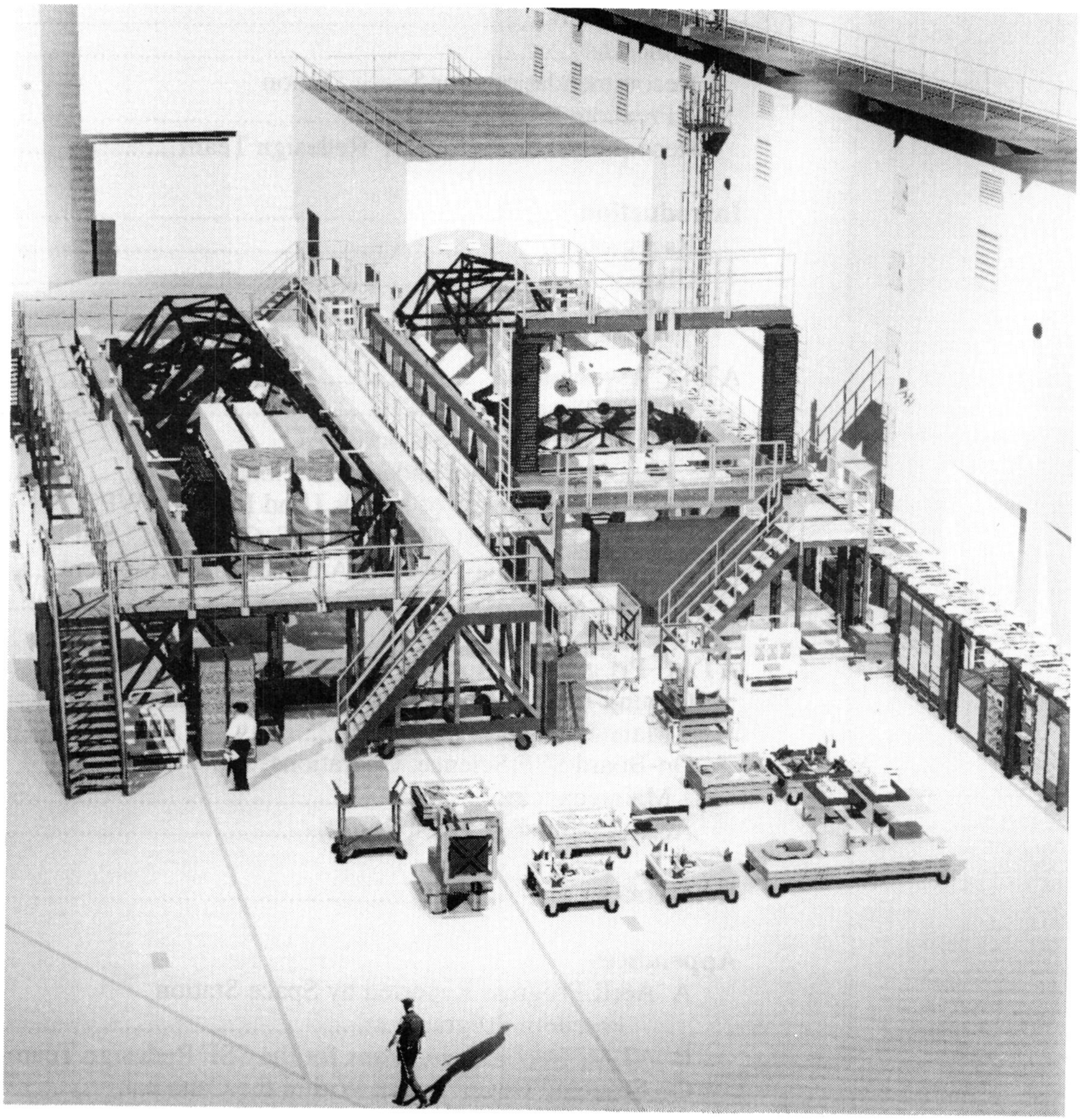
Table of Contents



Space Station Processing Flow Design Visualization

McDonnell Douglas Space Systems in support of Kennedy Space Center has developed a capability for design visualization through computer generated images. This capability has been applied to the Space Station Processing Flow (SSPF) at KSC. A three dimensional computer graphics database of dimensionally accurate graphic models of facilities, facility systems, ground support equipment, and payloads has been developed. These models are interchangeably used to develop, evaluate, and optimize Space Station Freedom payload processing flows through concept and design studies of access and protuberance, and mission and system integration.

Executive Summary

Background

In 1984, Congress directed NASA to develop and implement an Automation and Robotics (A&R) program with the intent to focus and transfer the A&R technologies into the U.S. industrial sector and economy by using Space Station Freedom as the focused application.

In response to the mandate of Congress, NASA in 1984 established the Advanced Technology Advisory Committee (ATAC) to review, assess, and report NASA's progress in carrying out its Congressional mandate. This is the sixteenth in the series of progress updates and covers the period of September 17, 1992 through March 18, 1993.

Concerns

A&R Technology Progress

ATAC is concerned that there still does not exist an Integrated Agency A&R Plan to evaluate, validate, and transfer advanced A&R technologies with SSF as the focused application.

With the budget limitations imposed on the SSF Redesign Process and with no Integrated Agency A&R Plan in place, ATAC is concerned that any potential progress in advancing and implementing automation and robotics technologies will be significantly impacted, if not entirely eliminated.

The Canadian A&R program consists of an integrated consortia of industry, Government, and academia members with the express intent of transferring the technology to the Canadian industry. ATAC is concerned that the U.S. does not have a similar program with focused national objectives.

The Congressional mandate that directed NASA to develop and implement an A&R program with the intent to focus and transfer the A&R technologies into the U.S. industrial sector and economy by using Space Station Freedom as the focused application is not being met.

Recommendations for Space Station Freedom Program

Automated Ground-Based Operations

Major payoffs of advanced automation technology include amplification of human capabilities, performance, and realtime decision making; significantly improved planning and scheduling for complex operations; and significantly improved systems fault management and recovery planning. Initial implementation efforts of advanced automation technology have significantly increased scheduling efficiency of STS flow processing at KSC and have enhanced STS mission control capabilities at the JSC Mission Control Center (MCC).

An advanced technology testbed has been established at JSC to evaluate and validate technology transfer of advanced automation into SSF ground-based

operations. Continued implementation and utilization of advanced automation for SSF will reduce the number of operations personnel required for SSF flow processing at KSC, for the Control Center Complex (CCC) at JSC, and for the SSF Payload Operations Integration Center (POIC) at MSFC. Automated ground-based operations will serve effectively as a basis for future migration of automation technologies on-board SSF.

ATAC recommends that SSFP continue the validation and implementation of advanced automation technology in SSF ground-based operations as a baseline infrastructure for reducing mission operations costs.

Ground-Controlled Telerobotics

A large portion (48%) of the SSF ORUs are being designed to accommodate telerobotic maintenance. Tests have been completed indicating that the up-link/down-link telemetry delays in telerobotic signals can be accommodated with implementation of proven telerobotic technologies. Implementation of ground control of telerobotics will provide a non-man-tended capability that could prove very useful throughout the Human-Tended Capability (HTC) SSF operational period and future long duration research.

The technology for the Canadian Space Agency robots and for the NASA JSC ground-controlled telerobotics console is available and compatible and enables successful ground-controlled telerobotics operation on SSF. The Canadian Space Agency, JSC Mission Operations, the Astronaut Corps, and the SSF robotics architect concur that certain robotic assembly, maintenance, and operations tasks should be performed from the ground to reduce crew EVA/IVA time requirements.

OACT, in conjunction with SSFP, Level I, should be encouraged to carry out space flight experiments to verify and validate the required technologies to meet the needs of SSF's mission requirements.

ATAC recommends that SSFP baseline the requirements for ground-controlled telerobotics for assembly, operations, and maintenance to reduce crew EVA/IVA time requirements and to increase science productivity during periods of no on-board crew presence.

Payload Data System

Current design for the SSF payload data interfaces was copied from the SSF core system. However, the payload data requirements are quite different. This mismatch of core design and payload requirements has resulted in insufficient science data downlink and uplink capability, insufficient remote configuration capability, and high-cost unique interfaces. Also, deviation from the current open architecture guidelines may constrain the ability to evolve in the future with system upgrades. These issues appear to have resulted partially from the fact that the PDS has not been considered one of the SSF "subsystems" and therefore has not been formally part of the CDR process. It is vitally important that the SSF payload data system have the capabilities and flexibility required to meet the needs of scientific payloads.

ATAC recommends that SSFP actively solicit Payload Data System requirements, and validate the on-board data management capabilities to address the needs of high volume science data and interactive remote operation.

Migration of Advanced Automation On-Board SSF

Very little, if any, advanced automation remains in the SSF on-board design as a result of restructuring limitations on weight, power, and budget during the past two years. However, progress has been made with advanced automation technology validation and insertion into SSFP ground-based operations, specifically at the JSC CCC, MSFC HOSC, and KSC processing flow facility. Ground-based operations can serve as an excellent test environment and proving ground for validating advanced automation applications prior to implementation on board SSF.

Advanced automation applications on-board SSF can significantly enhance capabilities for future SSF operational phases. However, no plan has been developed to identify the most appropriate applications nor the most appropriate process to accomplish migration of advanced automation from ground-based operations to on-board SSF.

ATAC recommends that SSFP complete the plan to migrate advanced automation from ground operations centers to on-board SSF with verification and validation conducted in the CCC, HOSC, and/or the SSPF advanced technology testbeds.

Integrated Agency A&R Plan

ATAC is still concerned that there does not exist an integrated Agency plan to evaluate, validate, and transfer the advanced A&R technologies to the SSFP. The Congressional mandate that directed NASA to develop and implement an A&R program with the intent to focus and transfer the A&R technologies into the U. S. industrial sector and economy by using Space Station Freedom as the focused application is not being met. Lack of a plan is particularly distressing in light of recent severe funding reductions.

An excellent example of an integrated technology development and transfer program exists at KSC. The Program integrates the user requirements with the overall advanced technology development program managed at KSC; this overall program includes the Center's Directionary Funds, Advanced Operations, OACT, SBIRs, Unsolicited Proposals, Technology Transfer and Resource Management, of which the latter two areas are still under development and not in an "operational" mode yet. OACT is encouraged to follow the programmatic philosophies used at KSC to increase the overall effectiveness of its technology transfer program.

ATAC recommends that OACT lead an effort in collaboration with SSF developers and users to define an integrated Agency A&R plan for automation and robotics technologies which focuses on SSF mission requirements and transfers the technologies to the U.S. industrial sector for increased economic competitiveness.

A&R Technology Transfer

"A vigorous advanced technology development program in each of the user program offices must complement OACT programs and enable smooth transition of technologies into new projects, consistent with user technology insertion plans" (reference: Assessment of Current Processes for Integration of Technology into NASA's Space Programs, March 1993).

The Level 1 Engineering Prototype Development (EPD) program has been the primary path for the integration of advanced technology into ground-based operations and on board SSF. Although constrained to a modest level of funding, the program has continued to be productive in addressing the operational issues of the SSFP which might benefit the most from advanced automation. The EPD approach of actively building teams of operational users from NASA flight centers and technologists from research centers is a model which should be adopted by all flight programs to enhance the integration and application of advanced technology.

The current Space Station redesign and financial pressures have forced the decision to discontinue funding most EPD activities in FY94. EPD is actively seeking options to transition tasks to alternative funding sources. Continuation of the EPD role is extremely important to validation and implementation of A&R technology.

ATAC recommends that OSSD insure the existence of a program within SSFP to develop, validate, and implement A&R technology in both ground-based and on-board operations.

Recommendations for SSF Redesign Team

ATAC is concerned that the Space Station is undergoing yet another mandated redesign which may have a detrimental effect on SSFP progress in implementing advanced automation and robotics. A reduced and/or eleminated A&R effort could further erode the industrial competitiveness of the nation in automation and robotics technology. ATAC provided the following Recommendations to the SSF Redesign Team on April 1, 1993 (see details in Appendix B).

Recommendation to Reduce SSF Life Cycle Costs

1. ATAC recommends that the SSF Revised Program continue the implementation and utilization of advanced automation technology in SSF Ground-Based Operations.

Recommendation to Enhance SSF Science Productivity

2. ATAC recommends that the SSF Revised Program provide the on-board data management capabilities to address the payload requirements of high volume science data and interactive remote operation.

Recommendation to Reduce Crew EVA/IVA Requirements

3. ATAC recommends that the SSF Revised Program initiate implementation and utilization of ground-controlled telerobotics for assembly, operations, and maintenance to reduce crew EVA/IVA time requirements.

Introduction

Background

Congressional Mandate

In 1984, Congress directed NASA to develop and implement an A&R program with the intent to focus and transfer the A&R technologies into the U.S. industrial sector and economy by using Space Station Freedom as the focused application.

ATAC Establishment

In response to the mandate of Congress, NASA established, in 1984, the Advanced Technology Advisory Committee (ATAC) to prepare reports identifying specific Space Station Freedom (SSF) systems which advance automation and robotics (A&R) technologies. In March 1985, as required by Public Law 98-371, ATAC reported to Congress the results of its studies (ref. 1). The first ATAC report proposed goals for automation and robotics applications for the initial and evolutionary space station. Additionally, ATAC provided recommendations to guide the implementation of automation and robotics in the Space Station Freedom Program (SSFP).

A further requirement of the law was that ATAC follow Space Station Freedom's progress in this area and report to Congress semiannually. In this context ATAC's mission is considered to be the following.

ATAC Mission

Review, assess, and report NASA's progress in carrying out its Congressional mandate for A&R technology development and application to Space Station Freedom. Specifically, independently review conduct of the Space Station Freedom Program to assess applications of A&R technology with consideration for safety, reliability, schedule, performance, and cost effectiveness (including life-cycle costs). Based upon these assessments, develop recommendations to enhance A&R technology application, and review the recommendations with NASA management for their implementation. Report assessments and recommendations twice annually to Congress.

The Space Station Freedom Program is charged with developing a baseline station configuration that provides an initial operational capability and which, in addition, can be evolved to support a range of future mission scenarios in keeping with the needs of space station users and the long-term goals of U.S. space policy.

The ATAC has continued to monitor and prepare semiannual reports on NASA's progress in the use of automation and robotics in achieving this goal. The reports are documented in the ATAC Progress Reports 1 through 15 (refs. 2-16). Progress Reports 1 through 5 covered the definition and preliminary design phase (Phase B) of Space Station Freedom. Progress Reports 6 through 10 covered the startup of the design and development phase (phase C/D) of the SSF. Reports 11 and 15 have covered the restructured design of SSF which was required as a result of SSFP budget reductions in FY 1991. Phase C/D will lead to a completely assembled station to be operational in the late 1990s.

ATAC Progress Report 15, like previous ATAC reports, received wide dissemination. ATAC Progress Report 15 was distributed in the following categories:

Congress	25 copies
NASA	235 copies
Industry	110 copies
Universities	50 copies
CSA, ESA, NASDA	5 copies
GAO	2 copies
Coord. Committees	17 copies
SSF Redesign Team	6 copies
Total	450 copies

This report is the sixteenth in the series of progress updates and covers the period of September 17, 1992 through March 18, 1993. To provide a useful, concise report format, all of the committee's assessments have been included in the section "ATAC Assessments." This section of the report includes comments on SSFP's progress in responding to the ATAC recommendations in Report 15. Also, a summary of progress in A&R in the Space Station Freedom Program as written by the program is provided as an appendix. The report draws upon individual ATAC members' understanding and assessments of the application of A&R in the SSFP and upon material presented during an ATAC meeting held March 16-18, 1993, at KSC for the purposes of reviewing the SSFP A&R activities and formulating the points of this report.

Climate

Prior to the March 16-18, 1993 ATAC meeting at KSC to review the SSF progress and status for ATAC Report 16, ATAC was informed via the reference letter indicated below that the President "wants the current Space Station redesigned as part of a program that is more efficient and effective and capable of producing greater returns on our investment. The revised station program should strive to significantly reduce development, operations, and utilization costs while achieving many of the current goals for long duration scientific research. The Redesigned program must:

1. Provide a cost effective solution to basic and applied research challenges whose merit is clearly indicated by scientific peer review, significant industrial cost sharing, or other widely accepted method;

2. Provide the capability for significant long-duration space research in materials and life sciences during this decade;

3. Bring both near-term and long-term annual funding requirements within the constraints of the budget;

4. Continue to accommodate and encourage international participation; and

5. Reduce technical and programmatic risks to acceptable risks."

(Reference: Letter from NASA Administrator Daniel S. Goldin, to Officials-in-Charge of Headquarters Offices, Directors, NASA Field Installations, Director, Jet Propulsion Laboratory, dated March 9, 1993.)

ATAC is concerned that the Space Station is undergoing yet another redesign which may have a detrimental effect on SSFP progress in implementing advanced automation and robotics. A reduced and/or eliminated A&R effort could further erode the industrial competitiveness of the Nation. ATAC provided Recommendations to the SSF Redesign Team on April 1, 1993 (see details in Appendix B). However, ATAC has not been provided information on the SSF Redesign Process to determine if its concern is justified.

The international partners, in particular the Canadian Space Agency, have done an extraordinary effort in adapting their systems to accommodate the various design changes which SSFP has undergone. Though they have also been impacted by budgetary constraints, they have been willing to provide a system that satisfies the basic mission requirements of SSFP. The status of the Canadian SSF robotics program was again briefed to ATAC and the content of their program reflects a well integrated and focused robotics effort. **The technologies are developed by an integrated Canadian consortia of industry, Government, and academia members with the express intent of transferring the technology to the Canadian industry. ATAC is concerned that the U.S. does not have a similar program with focused national objectives.**

The Space Station Program Level I Engineering Prototype Development Program (EPD) activity has been a highly productive and cost effective program for the transition of advanced technology to address SSF operational issues. **The EPD approach of actively building teams of operational users from NASA flight centers and technologists from research centers is a model which should be adopted by all flight programs to enhance the integration and application of advanced technology.** EPD is commended for its efforts to coordinate with other NASA programs,

industry, DOD, academia, and other government organizations.

The advanced automation technologies being incorporated into the SSF CCC at NASA/JSC, into the HOSC at NASA/MSFC, and into the Processing Facility at NASA/KSC should not be affected by any SSF Redesign Process to any great extent. The ongoing work at these facilities is based on an open architecture concept that is vendor-independent and highly adaptable to changes in mission requirements and objectives. **ATAC commends their efforts for taking an aggressive approach to ensure that their ground-based system designs are robust, cost-effective, and adaptive to changes in the current dynamic environment.**

Concerns

A&R Technology Evolution

ATAC is concerned that with the budget limitations of the current SSF Redesign Process, SSFP Level I progress in advancing and implementing automation and robotics technologies will be significantly curtailed. Although the OAST-sponsored A&R program never met the Congressional intent in the establishment of the original technology program, the SSF Level I Engineering Development Program has been well focused and integrated and has begun to achieve success in validating the A&R technologies for transfer to SSFP's operational environment, specifically the ground-based systems.

ATAC is concerned that there still does not exist an Integrated Agency A&R Plan to evaluate, validate, and transfer advanced A&R technologies into the SSFP to

• Address and focus the mission requirements of the end user in accordance with the users' technology priorities and schedules;

• Verify and validate the technologies in the users' operational environment(s); and

• Transfer the technology to industry to increase the nation's industrial competitiveness.

With the budget limitations imposed on the SSF Redesign Process and with no Integrated Agency A&R Plan in place, ATAC is concerned that any potential progress in advancing and implementing automation and robotics technologies will be significantly impacted, or eliminated entirely.

The Congressional mandate that directed NASA to develop and implement an A&R program with the intent to focus and transfer the A&R technologies into the U.S. industrial sector and economy by using Space Station Freedom as the focused application is not being met.

Ground-based SSF Science, Operations, and Maintenance

With the ongoing Redesign Process, ATAC is concerned that the Redesign Team will not take advantage of the current work being done within SSF's CCC, HOSC, and the Processing Facility to incorporate advanced automation technologies leading to more cost-effective operations. The current designs are sufficiently robust that they can be easily adaptable to accommodate changing mission requirements with minimal cost impact.

ATAC urges that strong consideration be given to maintaining the current designs being pursued by the CCC, HOSC, and the Processing Facility design teams even though the initial design costs may be higher than that of older, conventional technologies. Total life cycle costs should be considered in the overall redesign analysis.

On-board SSF Science, Operations, and Maintenance

To increase the versatility of the SSF science, operations, and maintenance, more attention should be paid to the DMS interfaces which are required for support of the science needs. Since these interfaces/requirements are not part of the formal SSF design review process, several science payload requirements are not being been addressed resulting in a compromise of the science payload.

In addition, it appears that less crew time will be available for operation and maintenance of the science experiments especially the material sciences and plant sciences payloads. Sufficient robotics technologies are available to provide ground-based telerobotic operations of the on-board robotics systems. Use of this mode of operation will increase the overall effectiveness of the SSF as a science facility and decrease the EVA/IVA crew time required for these tasks.

ATAC urges that strong consideration be given to the implementation of a ground-based telerobotics control station for the CCC.

OACT, in conjunction with SSFP, Level I, should be encouraged to carry out space flight experiments to verify and validate the technologies required to meet the needs of SSF's mission requirements.

ATAC Assessments

Basis of Assessments

The ATAC assessments for this reporting period are based upon the committee's appraisals of progress in advanced automation and robotics for Space Station Freedom. A review of the progress toward the recommendations from ATAC's most recent report, Progress Report 15, will be discussed first, followed by a review of topics explicitly addressed during the March 16-18, 1993 ATAC meeting, and then a discussion of new A&R issues.

It is ATAC's understanding that Congress directed NASA to develop and implement an A&R program with the specific intent to focus and transfer the A&R technologies into the U. S. industrial sector and economy by using Space Station Freedom as the focused application. Due to the congressional budget constraints, the SSFP, as currently restructured, is focusing the incorporation of advanced A&R technology only into ground operations, however. OACT has not provided ATAC with sufficient information to determine relevance of its A&R program to SSF requirements and needs.

Assessment of Progress on ATAC Report 15 Recommendations

ATAC Progress Report 15 Recommendation I: Ground-Controlled Telerobotics.

"SSFP assess the need, due to SSRMS/ SPDM redesign, to operate robotic systems from the ground, and if required, incorporate ground controlled telerobotics as a baseline SSF capability."

SSFP Response to ATAC:

The SSFP is currently addressing the implementation of ground control of robotic systems to: (1) reduce on-board crew time during manned periods and (2) permit certain assembly, maintenance, and inspection functions to be performed during unmanned periods. At the last CSA/NASA Joint Program Review (JPR), senior management from both NASA and CSA expressed their commitment to pursue the implementation of ground control, pending a favorable outcome of the joint CSA/NASA study described below.

The CSA/NASA ground control study approach can be composed of three phases:

1. Feasibility demonstration.
2. Architecture development.
3. Cost/benefit analysis.

The first phase, the feasibility demonstration, has been completed and was presented to the ATAC at JSC in September 1992. The results of this phase indicated that safe and efficient ground

control of SSF robotic systems was feasible, assuming that the proper architecture of ground and on-orbit resources was provided. These results were supported by the Astronaut Office. Several participants in the test commented that any task could be performed via ground control if adequate training and operations time were provided. Hence, ground-controlled robotics could be expected to provide a number of benefits to Space Station. For example, remote inspection could assist in troubleshooting station system anomalies, just as the Shuttle RMS has proven invaluable as an inspection tool for surveying Orbiter tiles. Even though Mission Build 6 supports IVA checkout of the SSRMS, remotely powering up and checking out the MSS could also assist in anomaly investigation and spare manifesting throughout the life of SSF. Additionally, remote setup of the EVA site could help constrain overhead time problems and remote ORU changeouts could help reduce IVA crew time requirements. Based on the favorable outcome of the first phase, a JPR action was assigned to proceed to the second and third phases.

The second phase, architecture development, involves determining the best implementation of robotic ground control based upon the existing baseline designs for the ground and on-orbit systems which support robotic operations. Presently, the Mobile Servicing System (MSS) accommodates ground control as a growth option, and the thrust of the architecture development activity in this area would be to determine what modifications (if any) must be made to MSS hardware and software to support ground control as a baseline capability. The Control Center Complex (CCC) and the SSF distributed systems such as the Communications and Tracking System (C&TS) and Data Management System (DMS) presently support uplink of high-level commands and downlink of telemetry data and video. The architecture development activity in these areas will focus on determining any additional enhancements (such as predictive displays, data buffers, etc.) which would be necessary to support robotic ground control.

The third phase, cost/benefit analysis, will compare the costs associated with implementing the architecture developed in phase two against the benefits in crew time reduction and assembly/maintenance/inspection operations during unmanned periods. Change Requests to program documentation will be introduced, and the results of the cost/benefit analysis will be presented at the Space Station Control Board (SSCB). A favorable outcome to the SSCB presentation will result in authorization to proceed in implementing ground control in the SSFP baseline.

The study is scheduled to be completed by 1 June 1993, and the results will be presented at the following ATAC meeting.

As part of determining technical feasibility, defining architecture compatibility, and analyzing the cost/benefit ratio, the Level I Engineering Prototype Development activity has led the Program in developing and demonstrating robotic ground control options. Within the last eighteen months, advanced telerobotic local/remote control technology from JPL has been robustly developed and deployed to JSC in the Automated Robotic Maintenance for space systems technology integration testbed. This testbed is aligned with the baseline Space Systems Automated Integration and Assembly Facility at JSC and provides an ideal opportunity to showcase advanced technology options in parallel with baseline activities. JPL rehosted its local and remote control systems to be compatible with the JSC mission operations planning environment and the Ada-based SPDM/SSF robot control environment. They condensed their local/remote site software to run on just two machines, a Silicon Graphics based operator's workstation and a multiprocessor VME chassis, which has subsequently improved the technology transfer to the JSC operations activity. Ground-based task verification and determination of task partitioning between robot and astronaut has been performed. The system emulates a SPDM controller for teleoperations, shared control, and autonomous control as an augmentation to the operator. The system also allows off-line update of objects in the task scene with task simulation and preview prior to execution. The software has been tested and demonstrated by having JSC, as the local site, drive the JPL remote site controller to perform an autonomous docking task. Additionally, these techniques assist the astronaut in training to assess when to use teleoperation or shared/autonomous control augmentation for motions like moving around obstacles, grasping partially occluded objects, inspections, or insertions.

Unfortunately, recent budget pressures within the baseline Program have placed these advanced capabilities in jeopardy before final technology transfer has been completed. If both the local and remote site system technologies could be transferred to JSC, the baseline would have the ability to emulate the SPDM control capability and SPDM limitations to determine the detailed SPDM design accommodations needed for near and far term baseline support.

The completed system would provide a robust ground-based task verification environment for developing control task sequences, weighing human vs. robot task tradeoffs, and partitioning tasks in terms of efficiency and error reduction. This also allows ground operators to update positions of objects in the workcell in the event of partial obscuration; and to develop robot control workarounds (autonomous augmentation for grasping and positioning) given obstacles, shadows, and obscurations through simulation and task preview. Command sequences could then be transmitted up to the SSF operator. Finally, the system would provide a flexible astronaut training medium for determining the most efficient way to perform tasks, structuring command sequences, and dealing with off-normal task environments like obscurations, shadows, and limited views.

The SSFP hopes those organizations within the Agency with the explicit charter of validating innovative advanced concepts consider Freedom a valuable customer and continue the transfer of advanced telerobotic technology into the baseline Program.

ATAC Assessment:

The Space Station Program made outstanding progress on this recommendation. Through meetings involving Space Station Level II, Canadian Space Agency, Spar Aerospace, Johnson Space Center and the Jet Propulsion Laboratory, agreement was reached that the Space Station Freedom telerobots should be operated from the ground.

Ground remote operations technology is now accepted by the Canadian Space Agency, the Space Station Level II Robotics Architect, JSC Mission Operations, and the Astronaut Corps as the best solution to increasing productivity of telerobotics on Space Station.

However, even though the need for Ground-Controlled Telerobotics is recognized by critical participants, the program will have to apply for funding to incorporate the technology as a baseline capability for both the Canadian and U.S. parts of the system. Currently, this funding need is overshadowed by the Space Station redesign activity. However, this recommendation and technology become even more important in a scaled back Space Station. Ground-controlled telerobotics should be used in human-tended phases of the operations and to free up astronaut time for science experiments during crewed operations. Ground-controlled telerobotics supports the current or any new Space Station concept as a more efficient and productive mode of operations.

The technology is now available to send "autosequences" from the ground which are quicker and safer than on-board teleoperation. The Astronaut Corps is in favor of Ground- Controlled Telerobotics. They feel they can perform any of the currently projected Space Station Freedom robotics tasks in space from a control station on the ground. Ground-Controlled Telerobotics is more cost effective to incorporate in any new Space Station concept from the beginning and not added in later.

Recommendation II: SSRMS/ SPDM Redesign.

"SSFP assess the impact of SSRMS/ SPDM redesign on telerobotic operations, specifically including task timelines and collision avoidance issues, and report results at the February 1993 ATAC review."

SSFP Response to ATAC:

Since the September 1992 ATAC meeting, the SPDM has undergone another design change which resulted in adding back a base Latching End Effector (LEE), allowing operations independent of the SSRMS when a suitable power data grapple fixture (PDGF) operating location is provided. Also, a more flexible architecture for accommodating end-to-end EVR operations (ORU handling, subcarrier accommodation, etc.) has been incorporated. However, the jointed body was not added back. An assessment of the net effect of these changes on telerobotic operations is currently underway.

At the SPDM PDR, held Feb. 8-12, 1993, a joint CSA/NASA Robotic Task Analysis Splinter to the Robotics Working Group was formed. This team will develop a standard approach for task analysis and will assess the crew operations time associated with operation of the MSS, including joint SSRMS/SPDM operations.

Due to these recent changes and solution-oriented activities, SSFP requests that this response be considered a status report, and that an extension to the next ATAC meeting be granted for a full response to this recommendation.

ATAC Assessment:

Space Station Level II is actively working the problems of defining telerobotic timelines, end-to-end robotics maintenance architecture, and robotics task verification. However, the impact of

the SSRMS/SPDM redesign on telerobotic operations has not been quantified. It is also overshadowed by overall Space Station redesign activities.

If there is a Space Station Remote Manipulator System and Special Purpose Dexterous Manipulator on a redesigned Space Station, then the operations impact of the two 7 degree-of-freedom Special Purpose Dexterous Manipulator arms on the end of the 7 degree-of-freedom Space Station Remote Manipulator needs to be analyzed for operations timelines and the complexity of teleoperations from onboard the Space Station.

An automatic collision avoidance system has been incorporated by the Canadian Space Agency on the Special Purpose Dexterous Manipulators for collision avoidance of its own two arms. Collision avoidance with the environment is left to the operator of the system.

Since the work on this recommendation is in process, Space Station Level II offered a more extensive briefing at the next ATAC meeting. ATAC has requested that another briefing be given on this recommendation at the next ATAC meeting.

Recommendation III: Data Management System.

"SSFP conduct a system simulation and analysis of DMS (SDPs, MDMs, sensors, and effectors) in a simulated operational environment to determine the computational reserve of the restructured DMS and its capability to meet the mission objectives and requirements."

SSFP Response to ATAC:

While the SSFP agrees with the intent of this recommendation and the value of performance simulation, we are continually balancing the costs and benefits of additional analysis tools versus applying resources toward mitigating known risk areas. Ideally, the Program would already have a dynamic simulation of its entire computational system, and at one time this was done, but as funding resources were reduced year by year, two things happened. First, system engineering resources had to be redirected from simulation to redesign activities, and second, the data system architecture went through a series of simplifications and reductions (e.g., Turbo, Scrub, Restructuring). The resultant architecture having fewer processors and fewer inter-system interactions was more amenable to simpler modeling techniques. To the extent possible, the SSFP has aggressively conducted Data Management System performance assessments. Consequently, the SSFP has a variety of DMS performance-related activities which have served to influence design and development tradeoffs. Although none of these individual projects have been scoped to develop a comprehensive dynamic flight system simulation, activities to date have effectively identified risk areas within the avionics architecture and some amount of coordination and correlation between individual simulation projects has taken place.

These individual simulations currently address two concerns. Core system developers are determining whether there is adequate processing and memory resources in the SDPs and MDMs. The Payload community efforts are directed at determining how the core DMS behaves and how a payload interfaces to it.

Ten significant modeling and simulation projects were found by canvassing the SSF program. Frequently used discrete event tools were Network II.5 and BONES, however, the most significant DMS modelling effort relative to its influence on DMS design is the SDP and MDM Resource Model which is a static model not a simulation. All activities address the rechannelized 18 bus architecture from MB 1 through HTC. Although these modeling and simulation tools have not been consistently applied in a system engineering process encompassing top-level architectural tradeoffs, functional allocations and performance measurement, they have adequately supported the analysis needs of the development organizations. Level I is currently assessing the value a dynamic DMS performance simulation would now provide and the feasibility of cost effectively developing an end-to-end configuration (i.e., ground operations, C&T, core DMS, subsystem MDMs, ORU firmware controller and the payload network).

Overview of Key Active Projects:

1. SDP and MDM Resource Model.

This spreadsheet estimates cyclic processing and memory loads and is the primary analysis tool used by the DMS development community to determine if the design fits within hardware resource allocations. The model is maintained by SSEIC, MDC, and IBM. All work packages actively supply inputs, support ongoing iterations and rely on the results in their design activities. It is used by the Software Design Architecture Team to partition and allocate resources and results are routinely reported at design reviews. It is a static model and not a dynamic simulation. Communication network resources are not modeled.

Recently, IBM has conducted an internal review of its design and development approach and is actively moving to enhance its resource models from static to dynamic performance simulations.

2. Integrated Functional Distributed Systems Assessment.

This effort evaluates how the SSF distributed systems handle operational scenarios and whether requirements are properly allocated to system functions. This assessment supports Level II SE&I and is performed by Space Station Engineering and Integration Contractor (SSEIC). Although it is comprehensive and uses a recognized system engineering tool, it addresses nominal DMS performance.

3. Payloads.

Multiple projects are underway to help understand how a payload would interact with the core DMS and C&T systems. For example, the MSFC Payload Projects Office conducts performance simulations of payload/DMS interface compatibility, hardware utilization throughput, and software execution.

4. Central Facilities Simulations.

The CSF and CAF use both simulations and emulators. The simulations are concerned with modeling real-world stimulus and response for purpose of flifgt software verification. They are not focused on DMS performance.

At the current time, the Program is working on architectural challenges identified in the static resource model. As the software architecture matures for the core periodic functions, dynamic simulations will be instrumental in validating the static model and will provide design criteria for implementing the more aperiodic portions of the Space Station architecture (e.g., the MPAC International Partner/ Payload/Core network traffic, ancillary data requests, etc). Hopefully, any bottlenecks, overhead drain, latencies, and backlogs identified by dynamic modeling and simulations and not already identified by the static model, will not require fundamental architectural changes to the existing computational design.

Given another impending redesign activity, the SSFP believes it would be prudent to wait until a decision is reached on the overall design before applying further resources in the performance analysis of the existing design. As the overall station design is decided, we must evaluate how a comprehensive dynamic simulation would complement the static DMS Resource Model and be used by the avionics community to more efficiently evaluate any specific avionics architecture options and understand the core DMS characteristics relative to their interface and service to payloads.

ATAC Assessment:

The design and operations importance and benefits of an end-to-end dynamic performance simulation of the DMS hardware and software including the payload data system apparently are not fully appreciated by the SSFP and WP2 management. Static spreadsheet resource models, such as the SDP and MDM Resource Model used by SSEIC, McDonnell Douglas Corp., IBM, and the Software Design Architecture Team to support all work packages, do not account for nonlinear dynamic effects of both nominal and contingent operations performance. The SDP and MDM Resource Model is not believed to model even core communications network resources.

This static approach assumes that any bottlenecks, overhead processing, latencies, and backlogs identified by dynamic simulations (yet to be developed) will not require major architectural changes. As the software architecture matures for the core periodic functions, dynamic simulations of the hardware and software including networks will be instrumental in validating the static model and providing design criteria for implementing the more aperiodic portions of the DMS architecture. The Ada run-time environment and rate monotonic scheduling will be difficult to simulate accurately. Currently, SSFP is working on architectural challenges identified in the static resource model.

Yet it will be critical to understand the behavioral dynamics of the DMS including the payload data system by CDR for any SSF design option.

> **Lack of an adequate customer/user orientation by SSFP has allowed (1) the payloads interface to be a cost growth item in WP2, (2) an astronaut patch panel with short life connectors to be the only reconfiguration mechanism of high rate data links for payloads, and (3) a host of other critical payload data-related issues affecting capabilities that do not meet user requirements.** There is not even a separate focus in the WP1 or WP2 CDRs for the payload data system portion of the DMS.

The SSFP has a variety of DMS performance-related activities which have served to influence design and development tradeoffs. Current activities are

targeted at point solutions, and sharing or coordination between these simulation projects occurs. These simulations currently address two concerns: (1) core system developers are attempting to determine whether there is adequate processing and memory resources in the SDP's and MDM's using the static model, and (2) the payload community wants to know how the core DMS behaves and how payloads interface to the core DMS.

Ten significant simulation projects were identified by the SSF program. All these activities address the rechannelized 18 bus architecture from MB 1 through HTC. However, none of these projects have been scoped to develop a top-down, comprehensive, end-to-end DMS simulation. Neither have these simulation tools been consistently applied in a system engineering process encompassing top level architectural tradeoffs, functional allocations and performance measurement.

The SDP and MDM Resource Model is a static spreadsheet model which estimates cyclic processing and memory loads and is the primary analysis tool used by the DMS development community to determine if the design fits within hardware resource allocations. All work packages actively supply inputs, support ongoing iterations, and heavily rely on the results, which are routinely reported at design reviews.

The Integrated Functional Distributed Systems Assessment effort evaluates how the SSF distributed systems handle operational scenarios and whether requirements are properly allocated to system functions. Although it is comprehensive and uses a recognized system engineering tool, it addresses only nominal DMS performance and functions.

Multiple SSFP projects are underway to help understand how a payload would interact with the core DMS and C&T systems.

Two recent events are promising. IBM has conducted an internal review of its design and development approach and is actively moving to enhance its resource models from static to dynamic performance simulations. Level I is currently assessing the feasibility of addressing an end-to-end configuration including ground operations, C & T, core DMS, subsystem MDMs, ORU firmware controllers, and the payload network.

In summary, the ATAC assessment is that the SSFP needs to move quickly to complete its evaluation of the feasibility of developing and using an end-to-end dynamic DMS performance simulation. The SSFP should already be using a dynamic simulation of its entire computational system. The SSFP choice to date seems to allow the higher risk and potentially higher cost approach of understanding dynamics only after major architecture implementation decisions affecting users and core elements have been decided in CDR.

Recommendation IV: CCC Advanced Technology Testbed.

"SSFP continue to support and encourage testing of new automation technologies from Level I EPD and OAST in the CCC advanced technology testbed for migration into the CCC."

SSFP Response to ATAC:

The Control Center Complex (CCC) orbital control facility provides for the ground operations of both Space Station Freedom and the on-orbit phase of the Space Shuttle. The Mission Operations Directorate (MOD) has ensured that the CCC architecture is modular and distributed in order to provide for incorporation of automation and technology applications in support of both programs.

In MOD's endeavor to provide for evolution to new technologies in the CCC, the CCC Advanced Technology Testbed has been established. This testbed provides the path for early evaluation and integration of new technologies into the CCC operational environment. It will also allow early investigation of new applications by the flight controller user community with minimal impact to ongoing work requirements.

The CCC Advanced Technology Testbed is currently being used to evaluate Level I Engineering Prototype Development (EPD) fault management models for the Thermal Control System (TCS), Electrical Power System (EPS), and the Environmental Control and Life Support System (ECLSS). The MOD Models Assessment Team (MAT) is the forum that provides the assessment of these SSFP models.

The Models Assessment Team evaluation of the TCS Automation Project (TCSAP) developed by Johnson Space Center was completed in January 1993, and the results were extremely positive. The thermal control system mission control team was favorably impressed with the application, and unanimously decided to pursue the use of TCSAP as part of their operational

capability in the CCC. Per the MAT recommendation, work to integrate TCSAP with the CCC Fault Detection and Management (FDM) system and Extended Realtime Failure Environment Analysis Tool (ERF) has already begun. As part of this early integration effort, a prototype interface between TCSAP and ERF is being developed, which will be tested and evaluated in the CCC testbed by August 1993.

Preparations are being made for the evaluation of the Level I EPD fault management models for EPS. The evaluation of the Space Station Module/Power Management and Distribution developed by Marshall Space Flight Center began March 1, 1993. Similarly the evaluation of the Power Management and Control Automation Project developed by Lewis Research Center is scheduled to begin April 19, 1993. The expected results of the EPS MAT evaluation will be a recommendation to provide a combined power management application to support both primary and secondary power systems. The evaluation of the EPD ECLSS model is scheduled to begin in August 1993.

In addition to the evaluation of Level I EPD tasks, MOD has been working with the Office of Advanced Concepts and Technology (OACT) to determine what technology developments can be leveraged in support of CCC automation. Several operations technology proposals were submitted to OACT in January 1993 by the MOD Control Center Systems Division (DJ). Technology tasks proposed to OACT included advanced fault management capabilities for the SSFP Data Management System and Propulsion System, and advanced diagnostic reasoning technology integration. Other tasks were proposed as well, which provide for institutional and multi program technology enhancements. Working relationships and project teams have already been established between MOD and technologists at Ames Research Center, Jet Propulsion Laboratory, and Johnson Space Center in support of these proposed tasks. The resulting technology applications, if funded, will also be evaluated in the CCC Advanced Technology Testbed and then migrated to the operational system.

In summary, the CCC Advanced Technology Testbed has been established to provide the path for the evaluation and integration of advanced technology into the CCC. MOD has worked extensively with Level I EPD, OACT, and NASA researchers to ensure that the CCC testbed will be utilized in order to achieve and maintain a state-of-the-art control center.

ATAC Assessment:

As described in Report 14, in response to ATAC's suggestion, the CCC Advanced Technology Testbed was established to provide a path for the evaluation of new technologies and their eventual migration into the SSF operational environment. The testbed provides the baseline set of CCC software tools and platforms to allow validation in a CCC compatible context, and will even be connected to the operational system so that new techniques can be evaluated concurrently with the conventional approaches, using realtime data.

The ATAC was very encouraged by the JSC Mission Operations Directorate briefing concerning the CCC Advanced Technology Testbed. It reflected a serious intent to install capabilities for demonstrating the advanced automated control technology for several major SSF subsystems, which had been developed under the Level I EPD (Engineering Prototype Development) program. Fault Detection and Management models for the Thermal Control Subsystem, the Electrical Power Subsystem, and the Environment Control and Life Support Subsystem are being delivered and incorporated into the testbed. Evaluations of each model will be performed this year by the operators and users of the respective subsystems to determine model applicability and identify recommended modifications. After a period of concurrent operation in both the testbed and the CCC, the new automation technologies would be considered certified for operational use.

By its plans for use of the CCC Advanced Technology Testbed and intent to certify and transfer automated control capabilities into the SSF ground operations, the SSFP has demonstrated its acceptance of the need for advanced automation technology. The ATAC applauds this trend and believes it can result in significant benefits in reducing the cost of operating SSF and improved monitoring of the performance of its vital subsystems.

Funding for the CCC advanced technology testbed was provided under the Level I EPD program, as was funding for development of the subsystems models for fault detection and management. The testbed is not being funded through the budget of the Control Center Complex. In light of the reduced budget for the EPD program and possible phaseout, the EPD program manager indicated that continued Level I support of the testbed's development and operation is in serious budgetary difficulty.

The ATAC believes that the CCC testbed is proving to be a critical tool in development of the CCC and its approach toward advanced automation. It recommends that continued funding for the testbed operation be made part of the CCC Space Station Mission Operations Program Office budget.

Recommendation V: Advanced Automation Technology Manager.

"OAST provide an Advanced Automation Technology Manager to SSFP Level I who will coordinate, integrate, and propose advanced automation technologies from within the research community to meet SSF mission requirements."

SSFP Response to ATAC:

The responsibility for this recommendation explicitly rests with the new Office of Advanced Concepts and Technology (OACT). For the record, the SSFP has neither been officially nor unofficially contacted by OACT in reference to addressing this recommendation.

Unfortunately, recent budget pressures within the baseline Program have placed internally-funded Engineering Prototype Development advanced technology applications in jeopardy before final technology transfer and insertion has been completed. The SSFP hopes those organizations within the Agency, such as OACT, with the explicit charter of validating innovative advanced concepts consider Freedom a valuable customer and continue the transfer of advanced automation technology into the baseline Program. The assignment of an individual with the recommendation's responsibilities would improve the technology supplier/customer relationship.

ATAC Assessment:

OACT has not provided a response to ATAC on this recommendation. As such, ATAC concurs with the SSFP response and reiterates its position that OACT (formerly OAST) has not met the original Congressional mandate in the establishment of the Automation and Robotics Program, i.e., that the A&R program should use SSF as the focus for the technology which, in turn, would increase the economic competitiveness and leadership of the United States. ATAC has contacted OACT with a proposal to implement this recommendation but have not yet obtained a response from OACT. **If OACT cannot provide an Advanced Automation Technology Manager to SSFP Level I, then ATAC urges SSFP Level I detail an Atuomation Technology Manager to OACT to directly manage and direct the technology efforts to ensure that the OACT automation funding allocated to technology efforts directly applicable to SSFP be directly managed by SSFP Level I to ensure that the technologies are kept focused on SSFP's technology requirements.**

A&R Status Review of Levels I and II; WP1, WP2, WP4, CCC, HOSC, PDS, OACT, CSA, KSC, SSFP, Flow Processing, and KSC Advanced Development

Assessment of Level I

The Level 1 Engineering Prototype Development (EPD) program has been the primary path for the integration of advanced technology for SSF. Although constrained to a modest level of funding, the program has continued to be productive in addressing the operational issues of the SSFP which might benefit the most

from advanced automation. The EPD program has established a mix of task demonstrations which focus on critical baseline issues such as resource allocation, failure mode analysis, redundancy management, flexibility of user interfaces, and operational and life cycle costs.

Since the last ATAC report, EPD progress on several fronts has been highlighted by the opening of the CCC advanced technology testbed. Flight controllers of the Mission Operations Division Model Assessment Team used the testbed to evaluate advanced thermal FDIR and EPS FDIR software. During baseline testing of the external bus on the thermal testbed, the Thermal Control System Automation Program (TCSAP) FDIR software was operated in parallel; it detected and diagnosed failures and faults before the baseline thermal testbed engineers.

Other recent accomplishments in advanced automation include: Continued support was provided for the application of portable computing on STS and development of the operations concept document for portable computing on SSF; the compass scheduler was used to develop payload operations plans for Spacelab payload tasks for STS-57; and two studies were initiated to identify opportunities for the application of advanced technology, one addressing SSF ground processing at KSC and the other as a joint activity with OACT to produce a technology road map to enable the enhancement of capabilities and increase task performance of the SSF robotic systems.

In the robotics area, JPL and JSC have linked their two telerobotics labs together over an existing Internet network and have demonstrated feasibility of ground remote operations by operating a robot at JPL from a ground console at JSC; collision avoidance capaciflectors have been shipped from GSFC to JSC for integration into their testbed for further test and evaluation; and flat target prototypes developed at JPL are being evaluated at JSC.

Other accomplishments in robotics include: evaluation of shared control software algorithms and local/remote control algorithm partitioning to handle time delay; use of User Macro Interface software to build and execute sequence of task steps (macros) under supervised control; and Operator Coached Machine Vision software to allow humans to correct and update vision-based world models has been transferred from JPL to JSC along with software to handle time force control with time delay.

The current Space Station redesign and financial pressures have forced the decision to discontinue funding most EPD activities in FY94. EPD is actively seeking options to transition tasks to alternative funding sources. The completion of the Failure Environmental Analysis Tool (FEAT) and FDIR tasks is considered extremely important to migrate advanced failure management automation into the CCC.

The EPD activity has been a highly productive and cost effective program for the transition of advance technology to address SSF operational issues. **The EPD approach of actively building teams of operational users from NASA flight centers and technologists from research centers is a model which should be adopted by all flight programs to enhance the integration and application of advanced technology.** EPD is commended for its efforts to coordinate with other NASA programs, industry, DOD, academia, and other government organizations.

Assessment of Level II

Major progress was made by Space Station Level II in integrating robotics across Work Packages and International Partners and resolving overall robotics maintenance issues.

Space Station Level II effectively manages its Robotics Working Group to address and review integration issues. The Robotic Systems Integration Standards Volume I (Robotic Accommodation Requirements) and Volume II (Robotic Interface Standards) are being updated and used as the primary tool for configuration management. Joint Program Reviews were held with the Japanese (NASDA) and Canadian (CSA) robotics partners. The revised Robotic Systems Integration Standards Volume I revision will include requirements for compatibility with the Japanese Remote Manipulator System Small Fine Arm. The Orbital Replacement Unit workload for the Special Purpose Dexterous Manipulator remained stable at 338 units representing a 48% offload of work from astronaut EVA to robotics.

Robotics interface testing continues at Johnson Space Center and the Canadian Spar Aerospace Limited. The focus is on the feasibility of robots for each Orbital Replacement Unit operation. To verify that the robotic operations can be performed, two documents will be prepared. The first document, the Robotic Systems Verification plan will define the overall program level approach and plans for robotic systems verification. It will

ensure that the system performance for force, reach, etc. meets specifications and that the robotic systems can perform designated assembly and maintenance tasks by referencing lower level documents and establishing responsibilities among the international development community. The second document, the Mobil Servicing System Integration and Verification Plan will detail integration and verification plans between CSA and NASA establishing intersite deliverables. ATAC endorses this activity for verification planning and documentation and recommends that they be baselined into the Space Station Freedom Program.

Space Station Level II developed a conceptual architecture for end-to-end robotics maintenance. Prior to developing this architecture, it would have been impossible to use robots to unload the Unpressurized Logistics Carrier provided by Work Package 1 (ATAC Report 15, Assessment of Work Package 1). Now the conceptual architecture includes subcarriers and adapter plates that make the system robot compatible. The specific interfaces and hardware implementation remain to be done. However, ATAC is encouraged by the progress which was made in making Space Station systems more robot compatible.

The Space Station Program made excellent progress in assessing the need for and feasibility of operating robotic systems from the ground. A report of testing done at the Johnson Space Center which shows the feasibility of Orbital Replacement Unit operations including ground controlled telerobotics modes will be issued shortly. Through meetings involving Space Station Level II, the Canadian Space Agency, Spar Aerospace, Johnson Space Center and the Jet Propulsion Laboratory, agreement was reached that the Space Station Freedom telerobots should be operated from the ground.

The Canadian Space Agency, the Space Station Level II Robotics Architect, JSC Mission Operations, and the Astronaut Corps concur that use of ground remote operations technology represents the best choice for increasing productivity of telerobotics on Space Station Freedom.

The Johnson Space Center Mission Operations Directorate has assumed the responsibility of planning with the Canadian Space Agency for the incorporation of Ground Controlled Telerobotics. Ground-Controlled Telerobotics is a joint Canadian/U.S. responsibility. The Canadian Space Agency and its prime contractor Spar Aerospace Limited are responsible for the space segment (remote site) of the telerobotic operations and interface; the Johnson Space Center is responsible for the operations control console (local site) of the telerobotic operations. It is critical that the system interfaces are compatible for Ground-Controlled Telerobotics. An initial assessment found the interfaces to be potentially compatible for Ground-Controlled Telerobotics. Funding will be needed to incorporate this technology into the baseline system.

Space Station life cycle costs will be greatly reduced by the use of robotics. ATAC urges the incorporation of Ground-Controlled Telerobotics into the baseline program.

Assessment of Work Package 1

The ATAC committee had been informed by the WP1 representative at the September, 1992 meeting that WP1 would not have a report for the March 1993 meeting. The reason was that no changes were anticipated in the status of automation and robotic functions under the purview of WP1 between the September 1992 reporting period for ATAC Report 15 and the March 1993 meeting to collect data for Report 16. As anticipated, there was no WP1 representation at the March meeting.

However, the concerns expressed by the ATAC committee in Report 15 are still valid. Although WP1 reported that they are committed to making the Unpressurized Logistics Carrier elements robot compatible, **there is considerable work remaining in establishing commonality in fasteners and operations timelines. Status of this activity should be reported to the committee. The ATAC committee also requested in Report 15 that WP1 conduct an analysis to verify that control of laboratory and habitat module systems can be satisfactorily accomplished from the ground. This action item is still open.**

Assessment of Work Package 2

The representative for WP2 did not attend the ATAC meetings conducted in March 1993, but did submit a detailed set

of briefing charts to the committee. This evaluation is based on the data contained in those charts without the added benefit of the dialogue which results from a formal briefing.

The CHeCS (Crew Health Care System) was baselined and will appear as a requirement in Rev. C of JSC 31013. This will permit a medical decision support system to be added to the medical equipment controller. Several COTS packages containing medical knowledge bases are available, but may not be in the format necessary for the medical controllers. If the knowledge bases are added to the CHeCS, this would constitute one of the first advanced automation systems onboard the SSFP. Advantages of this system would be to provide a common system for flight and ground that could standardize medical evaluations. This could potentially reduced the number of MDs required to support the operational phase of the Station.

ATAC commends WP2 for this effort to create an opportunity for incorporation of advanced automation in a system as critical as crew health, and encourages SSFP/ OACT to provide funds for conversion and validation of commercial medical knowledge bases for the medical decision support systems.

WP2 has now incorporated the RSIS (Robotic System Integration Standard) into their specifications and drawings through the Robotics Compatibility Requirements and RSIS Volume II amended documentation set. A statement of work applicable to the changes has been issued by the WP2 prime contractor to the subcontractors. A WP2 Robot Test and Verification Plan has been developed and incorporated into applicable System and Element Verification Plans. The WP2 Automation and Robotics Plan has been updated to reflect these changes in direction since the Program PDR was conducted. The number of robot compatible ORUs remains constant at 81, with no change since the last reporting period. Ongoing channelization activity resulting from last year's redesign may produce some changes to the count and renaming of the specific types of ORUs. Some changes have been made to WP2 structures to accommodate other WPs' robot compatible ORUs. These changes include hinged radiators and stabilization point on the structure. There has been progress in development of EVA ORU handling tools that will interface with the baselined RSIS interfaces. The SPAR-H handle and microconicals are examples.

The WP2 Robot Compatibility Requirements Document is the single source for consolidating and interpreting all WP1 robotic requirements. A second document, the Robot Test and Verification Plan identifies the verification methods to be used to validate each requirement. Acceptable methods are inspection, analysis, similarity, and demonstration and test. As a result of continuing budget restrictions, the WP2 prime contractor and the Johnson Space Center/Automation and Robotics Division are beginning to identify a significant portion of the verification testing to be conducted by JSC in the form of Track Tasks, a process used during the Shuttle Program to off-load some of the contractor tasks (a Track Task becomes a formal commitment on the part of JSC to perform the specified tasks and report the results back to the contractor). A statement of work defining the responsibilities, procedures and products is being developed. Status of this activity will be reported in future ATAC meetings.

The SPDM PDR revealed that design changes made by SPAR no longer match the baseline contained in the WP2 Robotic Compatibility Requirements Document. This WP2 document contains the SPDM design and interprets the SPDM capability for use in WP2. These changes will require reevaluation of interfaces and addition of H-fixtures and targets for stabilization on the front faces of the truss.

ATAC commends WP2 for the significant accomplishments that have been made in robot compatibility and the number of items baselined in WP2 documentation.

Assessment of Work Package 4

ATAC was provided briefings on the WP4 SSFP Engineering Prototype Development and on WP4 robotics activity.

The WP4 approach to automation is to prototype new techniques and evaluate and validate them within existing test beds or other development facilities using both operations and engineering personnel. Automation efforts are targeted for Engineering Support Center (ESC) and CCC monitoring and control of the Electrical Power System (EPS) and focus on automated monitoring of power system health and use of intelligent systems for fault detection, isolation and recovery. The goal is to maximize the availability of on-board power, with minimal human intervention, by rapid, intelligent reaction to anomalous situations. Specific areas of concern are reconfiguration of the EPS in response to varying power demand,

control of battery charge and discharge, thermal control and solar array pointing. Data assimilation that will collect and display only relevant and critical information to the human operator is also being considered. Analytical models that emulate the various subsystems are being developed.

Over the recent reporting period, WP4 has worked on automation of the battery monitoring system to improve the fidelity of analytical information and the usability of operations console displays. They have also demonstrated their work to WP1 and WP2, where it has been very well-received.

Funding reductions in the SSFP EPD have forced WP4 to reduce their activities in FY93 and face the possibility of no funding in FY94. The funding reductions in FY93 will eliminate functional modeling, which is critical to the fidelity of system fault processing. It will also eliminate on-line testbed verification activities, essential to testing the automated systems in a robust environment and to proving the validity of the approach to program managers. Termination of funding in FY94 will end all activity focused on automated failure detection and diagnosis for thermal control, power control and solar array pointing, and all efforts to upgrade the human-computer interfaces for EPS ground control.

The implication of the funding reductions is that the substantial improvements in system capability seen in the early prototyping activity will not be expanded to a broader application, and will not be effectively demonstrated in a robust testbed environment and subsequently migrated to the baseline ESC engineering or CCC operations activities. Only severe malfunctions will be diagnosed by the baseline system. Responsiveness of the spacecraft to power anomalies will then depend on human ability to diagnose and correct complex faults quickly and accurately.

In the robotics arena, WP4 reported that of the total of 231 external ORUs associated with the EPS, 202 have been designed to be robot compatible, and 21 human-tended but robot-cooperative. WP4 continues to consult with WP2 on the SSF maintenance activity where robotics will be required and is raising WP4-relevant issues including need for alignment guides and visual cues, changeouts for large ORUs, and the requirement for ORU temporary storage.

WP4 also held its CDR in March 1993. WP4 continues to support work in robotics verification and will assure that Robotic Standards and Interface System (RSIS) requirements are verified for their designs. WP4 is playing a major role in updating the RSIS. WP4 is also participating in the review of the Robotics Task Verification Plan, under development by SSFP Level 2 and CSA.

ATAC remains concerned that no funding is being provided to WP4 for testing ORU compatibility. Testing is essential to assure full understanding of the design implications of robotic operations. ATAC urges that the Space Station Program reconsider its decision to discontinue funding for WP4 automation activities. The value to the program in terms of increased platform utilization, accurate and consistent anomaly diagnosis, and potential reduced operations costs is substantial.

Assessment of Control Center Complex

ATAC was provided informative briefings at the review by the SSFP's design and implementation agent for Space Station Freedom control, JSC Mission Operations Directorate's Control Center Systems Division. Status and progress including intelligent systems in the CCC since ATAC's last review were provided. Progress was excellent. However, progress should continue, and is now seriously threatened due to budget reductions to both Engineering Prototype Development (EPD) funds and operations budgets.

The Control Center Complex (CCC) is comprised of ascent/entry and orbital control centers. The Mission Control Center(MCC) is transformed into an Space Shuttle ascent/entry control center, while the space station control comes from the Orbital Control Center (OCC), which combines Space Shuttle and SSF orbital support.

The CCC is designed to reduce operations and facility development costs for Shuttle and Space Station. The CCC major capability buildup has been identified as a series of deliveries and releases which are currently being defined and baselined. The CCC provides the basic core command and control capability for SSF, achieves replacement of existing MCC command and control capabilities by sharing the new SSF capability, and permits the removal of outdated MCC equipment to achieve major maintenance and operations recurring cost savings.

CCC delivery 1 release 1 was completed on schedule in December 1992 within budget. It provided commercial

off-the-shelf capabilities acceptable for CCC data distribution/monitoring, network management and security. It also provided effective use of industry standards to achieve effective application software portability. CCC delivery 1 release 2 is on schedule and within budget for a July 1993 completion. This release will include initial flight control room consoles and systems for on-orbit support.

A CCC advanced technology testbed was established to provide a path for the evaluation and migration of new technologies into the operational environment of the CCC. Technology developed in-house by NASA research organizations and industry can be installed on the testbed in order to evaluate its usefulness to controllers. The testbed provides the baseline set of CCC software tools and platforms in a test environment to enable the demonstration and evaluation of new technology in a CCC-compatible environment. Connectivity to CCC realtime data will provide the capability to evaluate new technology in parallel with realtime operations.

Since the last ATAC review in September 1992, demonstrations and evaluations of commercially available expert systems and other products have been performed in the testbed in order to help determine what baseline set of tools should be provided in the CCC. Evaluations of Level I EPD fault management models for the thermal control system and module power management and distribution have been performed in the CCC testbed. In addition, connections to additional facilities were provided in order to provide remote evaluation and file transfer capabilities.

CCC advanced technology testbed plans for the next six months include testbed support to additional advanced technology assessment activities and completing the testbed incorporation into the CCC architecture plans and schedule for processing in parallel.

The CCC Fault Detection and Management (FDM) subsystem provides support to both the Space Station Freedom Program (SSFP) and the on-orbit phase of the Space Shuttle Program (SSP). FDM provides automated fault detection and analysis of SSF and the Shuttle using a distributed architecture. The FDM design is modular to allow integration of advanced monitoring and diagnosis techniques with conventional monitoring techniques. A capability called Extended Realtime FEAT (FEAT is the acronym for Failure Environment Analysis Tool, a directed graph representation or model of failure modes of equipment) is used upon detection of a fault to perform integrated fault analysis. Level I EPD fault management models are being evaluated as additional monitoring and diagnosis capabilities for SSFP TCS, EPS, and ECLSS.

Extended Realtime FEAT (ERF) provides integrated fault analysis across subsystems and systems for both SSFP and SSP. ERF uses digraph analysis, heuristics, and fuzzy logic to provide a narrowed set of candidate failures based on the current configuration of the onboard system(s). ERF communicates with model-based reasoners, when necessary, to obtain a more in-depth problem analysis. ERF also provides hooks to allow integration with other future advanced capabilities, such as recovery planning. In short, ERF is the basis for integrated fault management in the CCC.

Since the last ATAC review, the ERF requirements definition has been completed, initial ERF prototype development has continued, and investigation of integration with more robust reasoners has started with the Thermal Control System Automation Project (TCSAP) as the pilot project.

ERF plans for the next six months include installing the initial ERF prototype in the CCC advanced technology testbed in June 1993 for user evaluation and feedback and providing the initial integrated ERF/TCSAP prototype to the CCC technology testbed in August 1993.

ATAC is concerned that due to SSFP budget limitations, Level I EPD funding for ERF is to be discontinued in FY94 resulting in major cost and operations impacts for many years with almost any SSF design option. SSFP must ensure the existence of a program to fund ERF.

The CCC is evaluating Level I EPD robust model-based reasoners for inclusion into the FDM subsystem. These fault management models provide more robust monitoring and diagnosis capabilities for SSFP TCS, EPS, and ECLSS. The JSC Mission Operations Directorate (MOD) Models Assessment Team (MAT) is the forum which evaluates these model-based applications based on user needs and facility integration requirements. Hands-on evaluations of each model are achieved in the CCC advanced technology testbed to determine its applicability and to identify any modifications required. Once modified as necessary to integrate within the CCC, these models will be used in the CCC advanced technology testbed concurrently with realtime operations. Once certified for operational

use, these models will be migrated to the operational system.

Since the last ATAC review in September 1992 the Level I models assessment activity has held an FDM models integration meeting in November 1992 to provide information on CCC, FDM, and ERF to model developers. Also, models assessment activities were completed for TCSAP in January 1993 and begun for the module power management and and distribution (SSM/PMAD) in March 1993.

Plans for the next six months for the models assessments include completing the evaluation of the module power management and distribution, doing an evaluation of the power management and control automation project (PMACAP), continuing integration of ERF and TCSAP, and beginning an evaluation of the environmental control and life support system advanced automation project (ECLSSAAP).

> **ATAC is concerned that due to SSFP budget limitations, Level I EPD funding for model-based monitoring, control, and diagnosis development to support CCC is being terminated in FY94 with major cost and operations impacts for each of many years into the future for almost any SSF design option. It is vitally important to ensure availability of needed funding.**

The work presently funded by the EPD supporting advanced automation insertion into the CCC should continue even if the EPD is terminated. Funding for these tasks can be obtained from other sources such as OACT if the EPD program is terminated.

In summary, ATAC's assessment is that CCC's use of modular, extensible, distributed workstation architecture, inclusion of knowledge-based systems, and establishment of the advanced technologies testbed are to be commended. The operations organization is committed to providing a smooth migration path for advanced automation into the CCC in order to maintain a state-of-the-art control center both now and in the future. **ATAC strongly opposes budget limitations that could terminate the outstanding progress being made.**

Assessment of Huntsville Operations Support Center (HOSC)

A brief presentation of overall progress was given at the ATAC review covering the MSFC Huntsville Operations Support Center (HOSC) as part of the Enhanced HOSC System (EHS). The SSFP Payload Operations Integration Center (POIC) is a project-specific component of the HOSC. Status was presented on the Data Acquisition and Distribution System, Payload Information Management System, Display Generation and Operation, System Monitor and Control, and Database Systems.

The EHS development has proceeded through a PDR and recently (February and March) through an internal Top Level Design Review. The CDR for the EHS is scheduled for March 1994. The EHS is a generic system that can support different Projects through the incorporation of Project specific application rountines.

Advanced technology is being introduced into the EHS to the extent resources permit by developing subsystem prototypes to test the various available components and techniques. ATAC feels this is the right way to enhance technology transfer that offers the best cost/benefit return to the Agency and yields multi-project benefits.

The Software Development Environment is being developed, scheduled for completion in October 1993. This will assure that all of the software (generic and Project specific) will be compatible, and should minimize the software integration problems and the test and checkout activities. The development approach utilized by HOSC is an excellent example of how, despite severe budget limitations, available resources are being used to maximum effectiveness.

Assessment of Payload Data System

Current design for the SSF payload data interfaces was copied from the SSF core system. However, the payload data requirements are quite different, as noted in the following comparison of core design versus payload requirements:

Core Design versus Payload Requirements

• Distributed realtime communication and control vs. minimum on-board interconnectivity.

• Low data rates vs. high volume data uplink and downlink.

• Batch file processing vs. near realtime remote telescience.

• Customized interfaces vs. commercial industry standards.

This mismatch of core design and payload requirements has resulted in insufficient science data downlink and uplink capability, insufficient remote configuration capability, and high cost unique interfaces. Specific issues include: video compression, lack of fault tolerance of the payload data processor (SDP-7), health and status data, control of downlink resource allocations, insufficient data and video uplink capability, use of a manual patch panel for data communications, use of the IEEE 802.4 data bus, use of an internal video system, limited on-board camera capabilities, video time base corrector, payload object database, and payload interface requirements document.

Also, any deviation from the current open architecture guidelines may constrain the ability to evolve in the future with system upgrades. These issues appear to have resulted partially from the fact that the PDS has not been considered one of the SSF "subsystems" and therefore has not been formally part of the CDR process. It is vitally important that the SSF payload data system have the capabilities and flexibility required to meet the needs of scientific payloads.

Assessment of OACT A&R Program

OACT did not present their A&R Program as requested by ATAC. Lack of participation by OACT may have been due to the recent organizational and personnel changes within OACT but this could not be confirmed by ATAC. In a separate meeting with OACT, information was provided to ATAC regarding the OACT A&R program. An assessment of the pertinent material received from OACT indicates the following conclusions and changes in direction:

• The previous A&R Program was a "fragmented program" without areas of specific foci that were driven by users' technology needs.

• Technology was not "proven in flight" which made the technology difficult to transfer to flight projects and to industry to increase the competitiveness of the Nation.

• The "NEW" (refocused A&R Program) will "focus on three application areas, expand outside involvement, and rapidly move to flight demonstrations." The new applications areas are operations, rovers, and robotics. The Mission Statement has been changed to "pioneer innovative, customer-focused space concepts and technologies, leveraged through industrial, academic and govenment alliances, to ensure U. S. commercial competitiveness and preeminence in space." The target operations R&T goals are to "reduce mission life cycle costs by 30%; reduce the marching army by 50%; increase payoff of science investment; and impact U. S. industrial productivity".

The content of the proposed OACT refocused A&R Program is more consistent with the recommendations made by ATAC in its previous reports. **Though the refocused OACT goals are laudable, ATAC still has a concern that there will be effective follow-through and a continuous assessment made on the progress of the program to meet the user needs, decrease mission operations costs, and increase the industrial competitiveness of the nation. This concern is based on the conduct and results of the previous OAST A&R Program over the last eight years relative to the total program investment.**

ATAC has also reviewed SSFP's assessment of the previous OACT Program including the technologies which are directly applicable to SSFP. The data indicates that the ATAC assessment is appropriate, i.e., the A&R program has not been focused on SSF's needs as originally intended by Congress when the A&R Program was established nor did it strongly contribute to the industrial competitiveness of the nation.

ATAC strongly encourages OACT to pursue and implement its refocused A&R Program including a reexamination of the individual elements of the total Program to ensure that the individual efforts are consistent with the refocused goals and do indeed meet the user needs as defined and accepted by the user. OACT is encouraged to present its refocused A&R and Data Systems Programs to ATAC at its next meeting to provide ATAC with an opportunity to review and comment on the restructured Program.

Assessment of Canadian Space Station Program

ATAC received a status report on the Mobile Servicing System (MSS) and a description of the Strategic Technologies in Automation and Robotics (STEAR) Program.

The Space Station Remote Manipulator System (SSRMS) Critical Design Review (CDR) was held in December 1992. Except for incomplete descriptions

of some components, no major issues were identified. The system level assessment of the remaining components will be addressed during the MSS CDR scheduled in July 1993.

The Preliminary Design Review (PDR) for the Special Purpose Dexterous Manipulator (SPDM) was held in February 1993. As reported in ATAC Report 15, the 5 degree-of freedom body of the original SPDM design was eliminated for cost reasons. The current base section includes both a standard SSRMS latching end-effector and a standard Power Data Grapple Fixture (PDGF). With both interfaces, the SPDM will operate from the end of the SSRMS or directly from a PDGF on SSF; however, without the body degrees-of-freedom and with the SPDM arm-lengths of 7 feet, the work envelope from a PDGF is limited. The majority of operations will require the SSRMS to carry the SPDM. When mounted on the end of the SSRMS, the SPDM requires additional stabilization to achieve a rigid base from which to operate. Rigidity is achieved by using one arm to grapple a nearby H-handle interface while using the second arm to perform the task. The analysis of the performance of the SPDM operating from the SSRMS was the major issue identified at the PDR. An additional issue was the incomplete analysis of failure tolerance and operational availability of the MSS.

STEAR is the Canadian program for the technology evolution of the MSS and to develop spinoff technology in A&R. The STEAR program was described in Appendix C of ATAC Report 12. This dual-use technology program, initiated in 1988, has resulted in establishing a number of new enterprises which are successfully marketing terrestial products such as an automated refueling system, a truck routing system, a laser terrain mapping system, and a force torque sensor.

Assessment of KSC Space Station Processing Facility

The main building for the launch site processing of the SSF is presently under construction at KSC. This building is located just east of the Operations and Checkout (O & C) building. This facility is large (457,000 square feet) and includes 137,000 square feet of office area, high bay areas, an airlock, support rooms, etc. The construction of this facility was started in 1991 and is scheduled to be completed August 1, 1994. It is presently about 70% completed.

In addition, a separate general hazardous payload processing facility is under construction with a scheduled completion date of December 1993. This facility will be used to process the Space Station propulsion module or any other hazardous components of Space Station.

The Space Station Processing Facility is state-of-the-art and Space Station design independent. However, it does assume the Space Station consists of module or elements and this facility provides eight generic module and element processing work stations. All of the utilities and services (power, fluids, etc.) are under the floor and accessible as required to each element work station. This facility is designed to support current Space Station requirements, and could support other derivatives resulting from SSF redesign. However, it may be inefficient to operate and maintain this facility for a simplified version of the Space Station with fewer demands.

ATAC feels considerable efficiencies can be obtained through the judicious and prudent use of payload specific robotic devices and automated checkout software. These could reduce the flow time and the number of personnel involved to produce considerable savings.

Assessment of KSC Space Station Ground Processing Flow

Space Station modules will arrive at the Kennedy Space Center via air, water, and land on various transportation vehicles. The processing of Space Station Freedom modules at Kennedy Space Center will take place in the new Space Station Freedom Processing Facility (SSPF), the Space Station Hazardous Processing Facility (SSHPF), the Vertical Processing Facility (VPF), and the Canister Rotation Facility (CRF). All non-hazardous Space Station modules will be processed in the horizontal mode in the SSPF, loaded into a Payload Canister, and integrated with hazardous modules in the VPF. Hazardous processing of the Space Station Propulsion Modules takes place in the SSHPF. All SSF modules will be moved to the Shuttle launch pad in the vertical position and installed into the Payload Changeout Room (PCR). No Space Station modules will be installed within the Shuttle Orbiter Processing Facility (OPF) where the current SpaceLab modules are loaded. This operational scenario prevents the interference of the processing and launch of Space Station modules and other Shuttle payloads which will be processed in the existing payload processing Operations & Control (O&C) high bay building and installed in the Shuttle in the OPF.

Space Station modules will enter the Space Station Processing Facility through the normal loading dock for small modules, and through the Airlock for large modules. The Space Station modules, test stands, GSE, and other large items will be moved throughout the high bay area on air bearing pallets. The modules of Space Station can be mated and tested in many combinations within the eight high bay test areas. Each high bay test area is provided with under-floor utility systems which will allow unrestricted use of the area for manuvering the test stands and modules on the air bearing pallets. The test and checkout stands are modular and can be integrated into many configurations to accommodate various Space Station module configurations. This flexibility of high bay test areas, modular stands, GSE, and air bearing pallets will allow the new Space Station Processing Facility to be used for processing almost any Space Station configuration that the program develops and be used for processing of almost any payload brought to KSC. Also, the development of new generic lifting devices will enable the processing of many payloal configurations.

Space Station propulsion modules are test mated, dry, within the SSFP, moved to the Space Station Hazardous Processing Facility to be loaded with hypergols and receive final mating with the Space Station modules in the Vertical Processing Facility. There are no hazardous processing functions that take place in the Space Station Processing Facility, except semi-hazardous processing of ammonia systems, which is currently being considered.

The new Space Station Test Checkout and Monitoring System (TCMS) is part of a computer CORE contract that is developing two sets of a generic computer hardware and software development system that will support the Space Station and a new system for Shuttle test and checkout (CCMS-II) that will replace the existing Shuttle Launch Processing System. The generic distributed hardware and software architecture of the TCMS will make it easier for the applications software developers to port old software into the system and develop new software. This configuration will also make it easy to integrate automation software into the system at any time during the life of the Space Station program. It will also allow the porting of expert systems developed for the Shuttle program into the TCMS to provide more automation for the ground support. With both the Space Station and Shuttle computer systems having the same architecture, it will make it easier for the two systems to share data and checkout responsibilites over an Ethernet to FDDI bridge system. The TCMS will provide test and checkout support throughout the Space Station integration process as well as provide support to the Principal Investigators during their experiment integration and test.

Considering the flexible modular design of Space Station facilities, GSE, and computer support systems, the KSC Space Station processing capability should easily support any configuration of Space Station designs as well as other future payloads that may need pre-launch processing at KSC.

Assessment of KSC Advanced Development

KSC's Advanced Development Program is an excellent example of an integrated technology development and transfer program at a NASA Center. The Program integrates the user requirements with the overall advanced technology development program managed at KSC; this overall program includes the Center's Directionary Funds, Advanced Operations, OACT, SBIRs, Unsolicited Proposals, Technology Transfer and Resource Management, the latter two areas which are still under development and not in a "operational" mode yet. The KSC Technology Development program is divided into six disciplines: Advanced Software; Electronics and Instrumentation; Fluids; Human Factors; Material Sciences; Non-Destructive Evaluation; Robotics; and, Atmospheric Sciences. Each fund source has a unique set of selection criteria that meet the needs of the fund source as well as the KSC needs. Criteria used for evaluation of the proposals for potential funding include: improvement of efficiency of ground processing activities at KSC; technologies that can support future programs; technology risk factors; and, quality of the overall Proposal. There is also a close collaboration with industry in developing the required technologies which, in turn, allows industry to utilize those technologies in other applicable programs. **OACT is encouraged to follow the programmatic philosophies used at KSC to increase the overall effectiveness of its technology transfer program.**

Specific comments about the KSC programs in the Advanced Development Program are as follows:

• Advanced Technology for SSF Ground Processing: The preliminary results of the MDSS study to investigate advanced technology for enhanced ground processing was presented. Initial processing improvement opportunity areas have been identified in the SSF Hazardous Processing Operations, the ground processing

management, the Logistics Support, the Ground Support equipment, Test and Checkout, and physical processing. Work is continuing to quantify the results and to identify specific cost-effective technology infusion opportunities. The goal is to identify and implement "generic" technology opportunities that are not dependent on the results of the SSF redesign and may use the Spacelab testbed for the initial technology verification and validation. The study is expected to be completed by September 1993. **KSC is to be commended for their aggressive efforts in investigating technologies to reduce the costs of SSF ground processing tasks through the applications of advanced automation technologies.**

• STS Ground Processing Technology Development: Many of the technologies developed for the improvement of the STS ground processing can also be applied to the SSF ground processing. The basic infrastructure, both hardware and software, for the support of the technology is directly transferrable to the SSF ground processing independent of the SSF redesign. Internal design tools developed by the McDonnell Douglas Space Systems Division at KSC have been effectively used to reduce the design and implementation costs. Examples are the use of Intergraph modeling software for the Ground Support Equipment design and fit tests and the use of advanced cabling design software tools.

• Advanced Software: The strategy employed for the selection of technologies applicable to KSC's advanced software applications are: to solve KSC's operational problems in a timely manner and to develop collaborative working relationships with other NASA Centers to minimize duplication of developmental activities and accelerate technology insertion into the operational environment. The most significant accomplishment to date has been the joint KSC/ARC development of the Ground Processing Scheduling System, GPSS, a constraint-based intelligent scheduling system configured to schedule tasks constrained by configurations and resouces of the Shuttle in the Orbiter Processing Facility. GPSS provides assistance to the KSC Flow Management in the conduct and optimization of Shuttle processing to reduce time in flow, problem reports, resource and configuration conflicts, scheduling manpower, and related costs. The software is currently being used to process all Orbiters at KSC with an average cost savings of $500K per flow with transition to operational status in the near future. **The GPSS Project is a very good example of what can be achieved if there is a close working relationship between a research center and an operational (user) center focused on an operational problem with specific technology requirements.** Other applications and the planned future directions were discussed—ATAC has a minor concern that the successful software strategy at KSC may be jeopardized if the Advanced Software Program takes on too many applications and dilutes its technology focus/emphasis in the process.

• Robotics: The objectives of the Robotics Program is to develop and demonstrate robust robotic technologies in ground-based operational environments that can eventually be transferred to space flight applications. The long term objective is to develop robust robotic systems capable of operating in complex, changing environments. The most advanced of these projects is the Automatic Radiator Inspection Device, ARID, jointly being developed by KSC, ESC, and LMSC. ARID will automatically inspect the Shuttle Orbitor radiators for defects twice during each OPF flow with the potential for consistent repeatability of measurements and reduction in the possibility of damage during inspection. This task is scheduled for completion during the latter part of CY-93 including documentation, certification, implementation, and installation.

New A&R Issues

Ground-Based SSF Science, Operations, and Maintenance

Automated Ground-Based Operations

Major payoffs of advanced automation technology include amplification of human capabilities, performance, and realtime decision making; improved planning and scheduling for complex operations; and improved systems fault management and recovery planning. These payoffs significantly reduce life cycle costs. However, throughout the life of ATAC there have been several major changes in the proposed Space Station design with little evidence, if any, that life cycle costs were considered in any design decisions.

There has been progress in the preliminary validation and implementation of advanced automation in ground-based operations. Initial implementation efforts of automation technology have significantly increased the scheduling efficiency of STS flow processing at KSC and has significantly enhanced STS flight control capabilities at the JSC Mission Control Center (MCC).

An advanced automation technology testbed has been established at JSC to evaluate and validate technology transfer

of advanced automation into SSF ground-based operations. Continued implementation and utilization of advanced automation for SSF will reduce the number of operations personnel required for SSF flow processing at KSC, required for the Control Center Complex (CCC) at JSC, and required for the SSF Payload Operations Integration Center (POIC) at MSFC. Automated ground-based operations will serve effectively as a basis for future migration of automation technologies on-board SSF.

ATAC recommends that SSFP continue the validation and implementation of advanced automation technology in SSF ground-based operations as a baseline infrastructure for reducing mission operations costs.

Ground-Controlled Telerobotics

A large portion (48%) of the SSF ORUs are being designed to accommodate telerobotic maintenance. Tests have been completed indicating that the up-link/down-link telemetry delays in telerobotic signals can be accommodated with implementation of proven telerobotic technologies. Implementation of ground control of telerobotics will provide a non-tended capability that could prove very useful throughout the Man-Tended Capability (HTC) SSF operational period and future long duration research.

The technology for the Canadian Space Agency robots and for the NASA JSC ground-controlled telerobotics console is available and will enable successful ground-controlled telerobotics operation on SSF. The Canadian Space Agency, JSC Mission Operations, the Astronaut Corps, and the SSF robotics architect concur that certain robotic operations should be performed from the ground to reduce crew EVA/IVA time requirements.

ATAC recommends that SSFP baseline the requirements for ground-controlled telerobotics for assembly, operations, and maintenance to reduce crew EVA/IVA time requirements and to increase science productivity during periods of no on-board crew presence.

On-Board Science, Operations, and Maintenance

Payload Data System

A major justification for the Space Station has been to support the science community. However, there has been poor communication between the Space Station program and the science community concerning provision of adequate on-board capabilities to meet the science needs. Productivity of science payloads can enhanced through the implementation of on-board automation and robotics. The need for advanced automation to support on-board science will become even greater if the redesigned Space Station configuration precludes permanent crew presence for extended periods of time.

The SSFP Level I Multilateral Coordination Board has developed a Consolidated Operations and Utilization Plan (COUP) that delineates the needs of the science community. The information developed by this group has set standards and considerations that will be applicable to Space Station operations no matter what the design may be.

Current design for the SSF payload data interfaces was copied from the SSF core system. However, the payload data requirements are quite different. This mismatch of core design and payload requirements has resulted in insufficient science data downlink and uplink capability, insufficient remote configuration capability, and high cost unique interfaces. Also, any deviation from the current open architecture guidelines may constrain the ability to upgrade the system in the future. These issues appear to have resulted partially from the fact that the PDS has not been considered one of the SSF "subsystems" and therefore has not been formally part of the CDR process. It is vitally important that the SSF payload data system have the capabilities and flexibility required to meet the needs of scientific payloads.

ATAC recommends that SSFP actively solicit Payload Data System requirements, and validate the on-board data management capabilities to address the needs of high volume science data and interactive remote operation.

Migration of Advanced Automation on-Board SSF

Very little, if any, advanced automation remains in the SSF on-board design as a result of restructuring limitations on weight, power, and budget during the past two years. However, progress has been made with advanced automation technology validation and insertion into SSFP ground-based operations, specifically at the JSC CCC, MSFC HOSC, and KSC processing flow facility. Ground-based operations can serve as an excellent test environment and proving ground

for validating advanced automation applications prior to implementation on-board SSF.

Advanced automation applications on-board SSF can significantly enhance capabilities for future SSF operational phases. However, no plan has been developed to identify the most appropriate applications nor the most appropriate process to accomplish migration of advanced automation from ground-based operations to on-board SSF.

ATAC recommends that SSFP complete the plan to migrate advanced automation from ground operations centers to on-board SSF with verification and validation conducted in the CCC, HOSC, and/or the SSPF advanced technology testbeds.

A&R Technology Evolution

Integrated Agency A&R Plan

ATAC has witnessed the development of the SSFP Level I Advanced Development program into a mature Engineering Prototype Development program that has integrated the program customer with the technology developers at NASA Research Centers, industry, and Academia. Through this teaming, the EPD program has developed advanced automation technologies that will greatly reduce the life cycle cost of supporting the operations of the Space Station.

At the ATAC session 16, the Canadian Space Agency (CSA) presented an overview of their Space Terrestrial/ Interface (STEAR) program. This program matches Canadian Space Agency technology users with technology developers, academia and industry, and incorporates a strong dual-use technology plan. It is a highly structured program with similarities to the US Small Business Innovative Research program. The program has been working for five years and has been highly successful in that it has developed technologies for the Canadian Space Agency users and commercial products for industry.

The new charter of the Office of Advanced Concepts and Technology (OACT) includes the goal of teaming the NASA user and developer of technologies to assure that the technology will meet the goals of the user and help guide the development during the process. It is also directed to develop dual-use technologies to help assure that NASA technologies can be directed to developing commercial products for industry.

ATAC is still concerned that there does not exist an integrated Agency plan to evaluate, validate, and transfer the advanced A&R technologies to the SSFP. The Congressional mandate that directed NASA to develop and implement an A&R program with the intent to focus and transfer the A&R technologies into the U. S. industrial sector and economy by using Space Station Freedom as the focused application is not being met. Lack of a plan is particularly distressing in light of recent severe funding reductions.

ATAC recommends that OACT lead an effort in collaboration with SSF developers and users to define an integrated Agency A&R plan for automation and robotics technologies which focuses on SSF mission requirements and transfers the technologies to the U.S. industrial sector for increased economic competitiveness.

A&R Technology Transfer

"A vigorous advanced technology development program in each of the user program offices must complement OACT programs and enable smooth transition of technologies into new projects, consistent with user technology insertion plans" (Reference: Assessment of Current Processes for Integration of Technology into NASA's Space Programs, March 1993).

The Level 1 Engineering Prototype Development (EPD) program has been the primary path for the integration of advanced technology into ground-based operations and on-board SSF. Even though constrained to a modest level of funding, the program has continued to be productive in addressing the operational issues of the SSFP which might benefit the most from advanced automation. The EPD program has established a mix of task demonstrations which focus on critical baseline issues such as resource allocation, failure mode analysis, redundancy management, flexibility of user interfaces, and operational and life cycle costs.

The EPD activity has been a highly productive and cost effective program for the transition of advanced technology to address SSF operational issues. The EPD approach of actively building teams of operational users from NASA flight centers and technologists from research centers is a model which should be adopted by all flight programs to enhance the integration and application of advanced technology. EPD should be commended for its efforts to coordinate with other NASA programs, industry, DOD, academia, and other government organizations.

The current Space Station redesign and financial pressures have forced the

decision to no longer fund most EPD activities in FY94. EPD is actively seeking options to transition tasks to alternative funding sources. Continuation of the EPD role is extremely important to validation and implementation of A&R technology.

ATAC recommends that OSSD ensure the existence of a program within SSFP to develop, validate, and implement A&R technology in both ground-based and on-board operations.

ATAC Progress Report 16 Recommendations

Ground-Based SSF Science, Operations, and Maintenance

Recommendation I: Automated Ground-Based Operations.

"SSFP continue the validation and implementation of advanced automation technology in SSF ground-based operations as a baseline infrastructure for reducing mission operations costs."

Recommendation II: Ground-Controlled Telerobotics.

"SSFP baseline the requirements for ground-controlled telerobotics for assembly, operations, and maintenance to reduce crew EVA/IVA time requirements and to increase science productivity during periods of no on-board crew presence."

On-Board SSF Science, Operations, and Maintenance

Recommendation III: Payload Data System.

"SSFP actively solicit Payload Data System requirements, and validate the on-board data management capabilities to address the needs of high volume science data and interactive remote operation."

Recommendation IV: Migration of Advanced Automation On-Board SSF.

"SSFP complete the plan to migrate advanced automation from ground operations centers to on-board SSF with verification and validation conducted in the CCC, HOSC, and/or the SSPF advanced technology testbeds."

A&R Technology Evolution

Recommendation V: Integrated Agency A&R Plan.

"OACT lead an effort in collaboration with SSF developers and users to define an integrated Agency A&R plan for automation and robotics technologies which focuses on SSF mission requirements and transfers the technologies to the U.S. industrial sector for increased economic competitiveness."

Recommendation VI: A&R Technology Transfer.

"OSSD ensure the existence of a program within SSFP to develop, validate, and implement A&R technology in both ground-based and on-board operations."

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Appendix A

A&R Progress Reported by Space Station Freedom Program

The Space Station Freedom Program (SSFP) is applying A&R technologies to the design, development, and operation of the baseline Space Station when found to be appropriate within the context of overall system design, to have a favorable cost-to-benefit ratio, and where the enabling technology is sufficiently mature. A&R technologies are experiencing rapid change, exhibiting varying levels of technology readiness, and have unique requirements for successful integration with conventional design approaches and system engineering methodologies. Consequently, the provision for design accommodations and mature technologies which permit the program to fully capitalize on A&R advances during the development and evolution of the Space Station is an important consideration. The program intends to leverage the significant momentum in A&R research and technology development within NASA, other government agencies, industry, and academia. Progress by the SSFP is described in the following sections.

Level I A&R Progress

The Advanced Programs activity at Level I was initially divided into two major components, Evolution Studies and Advanced Development. A detailed overview of Advanced Programs was provided in ATAC Progress Report 7, Appendix B, "Overall Plan for Applying A&R to the Space Station and for Advancing A&R Technology." Additional information can be found in ATAC Progress Report 8, Appendix A, "OSS A&R Progress," and ATAC Progress Reports 9, 10, 11, 12, 13, 14, and 15 Appendix A. Advanced Programs has been reorganized within the Level I Space Station Engineering Division to reflect the priorities resultant from Program Restructuring. The Advanced Development Program has been retitled Engineering Prototype Development and placed within the Systems Development Branch of Level I Engineering. This move more closely ties advanced technology developments to baseline issues and concerns and facilitates insertion of new technology where appropriate. Evolution Studies has been placed within the Systems Engineering and Analysis Branch to more closely align growth and evolution concepts with baseline scenarios.

Unfortunately, recent budgetary pressures have forced SSFP management to decide that Engineering Prototype Development activities can no longer be afforded. Consequently, SSFP plans to terminate program funding of EPD in 1994. SSFP will request that organizations with the explicit charter to promote and demonstrate advanced technology concepts (e.g., the Office of Advanced Concepts and Technology) will now consider Space Station as their primary technology customer. SSFP anticipates that these advanced technology development organizations will fund existing Space Station engineering prototyping activities.

During the remainder of FY93 the Engineering Prototype Development activity will reorient its funding priorities, in order to complete a subset of its most-critical baseline Space Station technology development tasks and assure sufficient opportunities for transition to other funding sources in FY94 and beyond.

Up to the end of FY93, the Engineering Prototype Development activity will continue to enhance baseline Station flight and ground systems capabilities by prototyping applications of advanced technology. These improvements will lead to increased system productivity and reliability, and help constrain operations and life cycle costs attributable to technological obsolescence. The activity evaluates and demonstrates technologies needed for Space Station's flight and ground systems by building user/technologist teams within flight and research centers, developing applications using a mix of conventional and advanced techniques, addressing transition and implementation issues, and evaluating performance of and documenting design accommodations for technology insertion and implementation. Specifically, cooperative arrangements have been pursued with the Office of Advanced Concepts and Technology; the Office of Space Systems Development Advanced Programs Development activity; the Office of Space Science and Applications; DARPA; and other Department of Defense programs.

As a result of these efforts, the SSFP is acquiring mature technologies, tools, and applications for key systems. In addition, performance specifications and design accommodations are being developed for the insertion of advanced technologies in both flight and ground systems.

Currently, the majority of the Engineering Prototype Development FY93 budget of $7.35M is dedicated to A&R applications and technology demonstration. Tasks are focused on fault detection and management, planning and scheduling, real-time telemetry distribution, advanced data management architectures, system and software engineering, and extra-vehicular robotics. Twenty-six tasks are divided between four work elements; flight and ground systems automation ($2.375M), Space Station data systems ($2.125M), advanced system and software engineering ($1.225M), and telerobotic and EVA systems ($1.625M). Sixteen of the tasks are leveraged by joint funding from the Office of Advanced Concepts and Technology, the Office of Space Systems Development Advanced Programs Development, Shuttle, and the Defense Advanced Research Projects Agency (DARPA). The joint funding adds approximately $7M to the tasks and enables Engineering Prototype Development to have considerably greater impact within the Station program than its funding level would indicate. Also worthy of note is the significant participation of Work Package contractors within the activity. Several have focused their own internal Independent Research & Development funding to address complem entary objectives of Engineering Prototype Development. The Small Business Innovative Research (SBIR) program is another significant facet of Engineering Prototype Development. Many of the activity's task managers participate in the SBIR program as proposal reviewers and task monitors. This joint funding and coordination significantly augments the resources devoted to building Space Station A&R applications, and facilitates technology transition to the baseline station.

In flight and ground systems automation, advanced fault detection and management applications are being developed for the Electrical Power System, the Environmental Control and Life Support System, and the External Thermal Control System. Additionally, a distributed architecture and an advanced failure analysis software package is being designed to support the integration of these techniques into the Control Center Complex baseline Fault Detection & Management (FDM) subsystem. The software package, Extended Real-time FEAT (ERF), will make use of digraph fault models created as a by-product of Space Station development. An advanced technology testbed for CCC applications has become operational and is now used for testing both ERF and the subsystem-specific FDM applications. Finally, a Spacelab scientific experiment has also served as the focus of applying advanced automation to support payload experimentation.

These applications focus heavily on Fault Detection, Isolation and Reconfiguration (FDIR) and provide a range of support in system status monitoring, safing, and recovery. All are a mix of conventional and Knowledge-Based System (KBS) techniques and each provides a powerful user interface to support interactions in an advisory mode. The primary benefits of these applications are improved system monitoring, enhanced fault detection and isolation capabilities, and increased productivity for Space Station mission control personnel and crew members. Increased system reliability via the detection and prevention of incipient failures, reduced IVA maintenance time, and better monitoring with fewer sensors are also added benefits of advanced FDIR techniques.

These tasks provide an understanding of the design accommodations required to support advanced automation (e.g., instrumentation, interfaces, control redundancy, etc.) and identify KBS implementation issues (e.g., integration of KBS and conventional algorithmic techniques, processing, data storage,

communication requirements, and software development, testing, and maintenance procedures) required for KBS development and support. As program pressure to reduce operations costs increases, the value and importance of these tasks likewise increases, for they provide the necessary R&D foundation to develop automated ground-based capabilities and to later migrate those functions back to space. The most significant accomplishments during this reporting period follow.

Advanced fault management knowledge based systems have been hosted on the Work Package 4 Power Management and Distribution (PMAD) testbed and are currently supporting baseline evaluations of the primary power distribution system. The conceptual design of a prototype electrical power system console position has been completed. This conceptual design integrates multiple expert systems, telemetry data, and a sophisticated human-system interface. Beginning in March 1992, MSFC contributions to this console software and its Electrical Power System (EPS) model began hands-on evaluation in the JSC Control Center Complex Advanced Technology Testbed by a Model Assessment Team (MAT) composed of Space Station flight controllers. MAT assessment of EPS models and console position software from MSFC and LeRC will continue for the next few months. This FDIR application serves as a bridge between the baseline testbed, the Work Package contractor's automation activities, the EPS Engineering Support Center, and the JSC Control Center Complex in support of Space Station power system operations.

Advanced automation fault management activities continue to support the baseline Environmental Control Life Support System (ECLSS). The advanced automation team has been supporting the baseline ECLSS requirements analysis team by providing advanced failure management models for ECLSS Failure Modes and Effects Analysis (FMEA). Additionally, expertise in automated diagnosis has been provided on those issues involving sensor placement and fault isolation which have arisen during the FMEA process. In particular, the task has recently provided sensor placement information to assist in verifying the diagnosability of the ECLSS Potable Water Processor.

The Thermal Control System (TCS) advanced fault management project has been integrated into the baseline TCS testbed at Johnson Space Center and continues to support the TCS verification process. The knowledge-based system has improved the TCS test engineer's ability to detect and diagnose system anomalies. During baseline TCS tests run at JSC in the first week of March, for example, the knowledge-based system detected and diagnosed a potentially dangerous pump power failure that the baseline thermal engineers and operators had not yet noticed. The TCS advanced fault management team has also been supporting the baseline TCS flight controller Model Assessment Team, Control Center Complex Fault Detection and Management (FDM) system integration, and Space Station Training and Verification Facility activities. After the TCS MAT evaluation was concluded in January 1993, the relevant JSC flight controller division chief was sufficiently impressed that he volunteered a flight controller as a liaison to the TCS advanced fault management team.

The Control Center Complex is currently assessing the feasibility of using EPD fault management models for Space Station operations and is developing a plan to integrate and evaluate these fault management projects within the control center architecture. The CCC Advanced Technology Testbed facility has become operational in the past several months. The TCS advanced fault management prototype was the first of the EPD tasks to be assessed in the CCC testbed, with the EPS PMAD now in progress and ECLSS fault management to follow. One recommendation of the TCS MAT was that the TCS automated FDIR software be moved into the CCC FDM baseline for TCS.

In support of the CCC FDM baseline, the Extended Real-Time FEAT activity is now underway. This activity addresses the need for an integrated, multi-layer FDIR architecture in the FDM baseline. ERF provides a tool for real-time FDIR using digraph models that have been generated as a side effect of Space Station development. The ERF architecture for the CCC will include FDM layers that will integrate ERF digraph software with other CCC functions and provide for the insertion of more advanced failure management technology.

Within Space Station data systems, the computer and network architectures of Space Station's Data Management System are being analyzed to provide increased performance and reliability and to determine long-range growth and evolution requirements. Additionally, advanced mission planning and scheduling tools are being developed and demonstrated for use on board Freedom as well as on the ground during Space Station operations. The most significant accomplishments during this reporting period follow.

The Advanced DMS Architectures task continues to evaluate existing and proposed uni- and multiprocessors; network, protocol and connectivity options; and data management software. Recently the task has developed test cases for DMS Standard Services, which the prime contractor had not planned but which were essential to the determination of the performance envelope of the DMS system. Development has begun on the only dynamic performance model of the DMS thus far, primarily for testing the dual string bus performance of the SDP. As a low cost evaluation capability, the architectures testbed continues to provide a focus for early verification of baseline and payload interfaces and to test access from payloads to DMS services. Results continue to be communicated to baseline personnel, the prime contractors, and the DMS subcontractors.

Evaluation of DMS system interface options and computer hardware and software interfaces continue to be supported via Shuttle Development Test Objective (DTO) tasks. A Macintosh portable, whose display format has the same general look and feel of the baseline Multi-Purpose Application Console (MPAC) display, was used successfully on STS-52 to investigate inventory stowage, on-board advanced failure analysis, and orbital map applications using graphics-based interfaces. ESA is borrowing one of the EPD Macintosh portables previously used for DTOs 1206 and 1208 for multimedia tests during Spacelab-D2 (STS-55). This joint activity continues EPD investigations into advanced concepts for portable computer operations.

The COMputer Aided Scheduling System (COMPASS) continues to improve in functionality and be used in a variety of scheduling applications. It is being used as a framework for building consensus within the Space Station scheduling community. In February, the COMPASS scheduler created a payload operations plan for STS-57. This plan, consisting of about forty SpaceHab tasks, was created in hours (rather than days) and converged initially-conflicting timelines submitted from MSFC and JSC. Advanced scheduling techniques from JPL are currently being integrated within the COMPASS framework, thereby providing more sophisticated automated scheduling functionality.

In December, EPD co-sponsored the Third Space Station Scheduling Workshop with OACT. This gathering was organized for the MSFC Mission Operations Laboratory, and was attended by over seventy timeline engineers and scheduling technologists to focus Space Station payload operations scheduling. Given the success of this workshop, another is tentatively planned at KSC in FY94 for Space Station ground processing scheduling.

In Advanced System and Software Engineering, tools, methodologies, and environments are being pursued to support the design, development, and maintenance of SSFP advanced software and system engineering applications. The most significant accomplishments during this reporting period follow.

The Failure Environment Analysis Tool (FEAT) is the standard SSFP tool for integrating and documenting system and subsystem Failure Modes Effects Analysis (FMEA) and hazard analysis data. The baseline version of FEAT supported by the Technical Management Information System (TMIS) is called the DiGraph Data System (DDS), which was released for general TMIS distribution last November. FEAT is now supported both within UNIX environments and on the Macintosh computer. The development of an intelligent editor which improves the creation of connectivity models is in progress.

A series of intelligent training systems is being prototyped for the Space Operations Training Division (SOTD) to demonstrate the value of Intelligent Computer Aided Training (ICAT) architectures and their feasibility for baseline Space Station training operations. The first prototype developed was for training on the Space Station External Thermal Control System. A prototype ICAT for familiarity training on the SpaceHab, called the SpaceHab Intelligent Familiarization Trainer (SHIFT) has also been developed jointly with the Office of Space Systems Development Advanced Programs Division. SHIFT is now in full operational use to train crews for SpaceHab missions. Additionally, ICAT tools have been provided to the SOTD for further evaluation and support of baseline training requirements. The SOTD has now accepted ICAT systems, in general, as part of its future baseline training needs.

The DMS Training Environment Emulator activity is prototyping a method of directly executing minimally modified Space Station flight software on inexpensive commercial processors without physical replication of flight interface hardware and busses. Given such a method, these low-cost task-training devices could offload expensive high fidelity DMS test facilities and also make DMS testing at multiple sites more affordable.

Telerobotic and EVA Systems focuses on IVA and EVA time- and safety-critical issues and concerns. Telerobotic activities pursue the reduction of IVA teleoperation time for dexterous robotics tasks, even in the presence of significant communications or computation time delays. Advanced telerobotics reduces an operator's workload by allowing the robot to control fine parameters (such as force exerted against a surface) while the operator directs the task. With improved sensing, planning and reasoning, and displays and controls, simple tasks such as unobstructed inspections and translations may be accomplished by remote operators in the presence of significant communications time delay. Supervised autonomy can help free the on-orbit crew from routine, repetitive, and time consuming inspection and maintenance tasks whenever possible. The most significant accomplishments during this reporting period follow.

Shared control software algorithms that permit simultaneous human and computer generated control, local/remote control algorithm partitioning to handle time delay, User Macro Interface software to build and execute a sequence of task steps (macros) under supervised control, and Operator Coached Machine Vision to allow humans to correct and update vision-based world models have been developed and extensively tested on the JPL Telerobotics Testbed. These technologies have now been transferred to the integrated PIT segment dual-arm workcell under development at JSC. JPL and JSC have linked their two telerobotics labs together over an existing Internet network and have demonstrated successfully that robotic hardware at JPL can be driven remotely from the JSC laboratory.

An Automated Robotic Maintenance testbed is under construction at JSC to integrate and evaluate advanced telerobotics technology in parallel with baseline robotic operations assessments. Work has concentrated on the assembly of an SPDM emulator, implementation of Ada software for the Robotic Forearm Pan and Tilt controller, integration of advanced technologies from JPL and GSFC, and overall operational checkout of the complete system.

To allow collision prediction and avoidance within a reduced computational environment, work continues on the evaluation of capacitance-based proximity sensors. Capaciflectors have been shipped to JSC for integration into their testbed and are currently undergoing further evaluation. A capaciflector was used last December on the OACT-sponsored "Dante" Antarctica rover.

The flat target project has made significant progress. This activity has prototyped a series of robotic targets that offer substantial savings within weight and volumetric constraints. It has received strong endorsements from Level II for its potential savings on Space Station ORUs and payloads. Flat target prototypes using microstructures have been designed, fabricated, and environmentally tested. Prototypes have been initially demonstrated in laboratory workcell environments. Initial flat target tests had tolerance problems due to inexact target manufacturing by JPL's in-house shop, but outsourcing the manufacturing has corrected the problem in the second batch.

Level II A&R Progress

Level II dedicates two full-time civil servants, several part-time civil servants, and a number of contractors to manage the integration of A&R in the baseline program. These individuals are responsible for ensuring integration across Work Packages and International Partners (e.g., Orbital Replacement Unit (ORU) standards, End-to-End Extravehicular Activity (EVA)/Extravehicular Robotics (EVR) Maintenance Study). They also address issues that impact at the program level, such as hand controller commonality, Mobile Servicing System (MSS) restructuring, and verification. Additionally, overall on-orbit assembly and maintenance responsibility resides at Level II; robotics play an extensive role in achieving these objectives.

Much of the Level II A&R activity is focused on the Robotics Working Group (RWG). This forum meets approximately three times per year at various locations to address A&R topics of interest at Level II and Level III. Some of the major topics addressed at recent RWGs include: CSA and NASDA Program Status, Robotic Systems Integration Standards (RSIS), ground control, robotics verification, and human/machine interfaces.

Additional Level II activities since the last ATAC report include efforts to assess the potential of ground control for robotic tasks and to develop task scripts and timelines to support EVA/EVR maintenance planning. Level II has also provided key support to various program reviews such as the SSRMS Critical Design Review (CDR), the SPDM Preliminary Design Review (PDR), and the WP-01 and WP-04 CDRs.

Since ATAC Report 15, significant progress has been made on the RSIS document and associated robot-compatible ORUs. Both RSIS Vol. I and Vol. II are being updated to their Rev. A versions; these modifications reflect more mature interface designs and should reduce cost impacts for robot-compatible ORU developers. RSIS interface testing is still underway at JSC and CSA/SPAR, with an emphasis on box-level testing. The Program Definition and Requirements Document (PDRD) Section 3 Table 3-55, which is the mechanism for identifying ORUs to be made robot-compatible, currently contains 366 ORUs, which comprise 41% of the external ORUs of Space Station and represent a potential 48% offload of EVA maintenance time to robotics. Proposals for modifications to Table 3-55 are entertained at each RWG, and a Change Request (CR) for a block update to the table has been submitted. Activities are underway by the Space Station Program Participants to verify RSIS compliance for each Table 3-55 ORU.

The End-to-End EVA/EVR Maintenance Study has progressed since the ATAC Report 15. In order to ensure that Space Station hardware, infrastructure, servicing agents, and logistics and operational concepts are compatible, efficient, and cost-effective for end to-end maintenance missions by EVA and robotics, a multi-center team has performed an end-to-end task assessment and developed and recommended an end-to-end infrastructure. The recommended end-to-end infrastructure includes both a hardware concept and an interface concept to accommodate ORU adapter plates, subcarriers, ORU handling at the worksite, and robotic setup of EVA worksites. The results of this study were presented to program management in November 1992. The overall end-to-end EVA/EVR maintenance architecture was approved, and actions were issued to refine the top-level architecture to a specific hardware and interface design and to document the associated requirements.

Level II is responsible for developing the program-level approach to robotics verification, which has two major components: robotic systems verification and robotic task verification. The purpose of the robotic systems verification activity is to ensure that robotic system performance (e.g., force, reach, etc.) meets specifications, and to establish intersite deliverables agreements between the Space Station Program Participants for components, simulators, etc. The robotic task verification activity ensures that robotic systems can perform their designated assembly and maintenance tasks, and establishes intersite deliverables agreements for mockups, computer simulations, etc. These activities fit into an overall framework defined in the Program Master Verification Plan.

Plans for robotic system verification are captured in two key documents: the Robotic Systems Verification Plan (RSVP) and the MSS Integration and Verification Plan (MSS I&VP). The RSVP defines the overall program-level approach and plans for robotic systems verification, and the MSS I&VP defines more detailed integration and verification plans for the MSS between CSA and NASA. These documents will be baselined prior the MTC Phase CDR in June 1993.

Plans for robotic task verification are documented in the Robotic Task Verification Plan (RTVP). The RTVP establishes the overall process for verification of robotic assembly and maintenance tasks, and will also contain assignments of verification methodologies for each robotic task along with facility schedules to support robotic task verification. This document is scheduled for baselining in the last quarter of FY93.

Work Package 1 A&R Progress

Work Package 1 automation activity has progressed to the Critical Design Phase of the Work Package 1 systems, mechanisms, and elements. The Predevelopment Operational System Test for the Environmental Control Life Support System (ECLSS) included testing the automatic control of the depress/repress function of the Atmosphere Control Supply Subsystem and the automated operation of the Atmosphere Revitalization Subsystem. The ECLSS Major Constituent Analyzer is a fixed-collection mass spectrometer that measures partial pressure of six gases (oxygen, nitrogen, carbon dioxide, water vapor, hydrogen, and methane) for atmosphere control and for automatic announcement by the Emergency Caution and Warning System. The Common Berthing Mechanism (CBM) motor controller automates operation of capture latches and power bolts of the CBM, providing a go-no-go to the crew. The berthing process is being validated in the 6-degree-of-freedom development test. A process has been developed which combines three systems: an eight-axis coordinated motion robotic welder, a Variable Polarity Plasma Arc welder, and an automatic seam tracker for welding Work Package 1 hardware. Baseline robotic activities have concentrated on support to program-wide robotic interface standards to ensure the compatibility of Work Package 1 ORUs to the

Unpressurized Logistics Carrier and Space Station robots.

Work Package 2 A&R Progress

Work Package 2 Space Station Automation & Robotics (A&R) is centered in the Project Integration Office of the Johnson Space Center (JSC) Space Station Projects Office. This office is responsible for defining requirements for A&R while the actual implementation is done by the various system and element organizations. Engineering management support from the institution comes mainly from the A&R Division which is organized into five branches: Intelligent Systems, Flight Robotic Systems, Robotic Systems Technology, Dynamics Systems Test (including the Space Station Automated Integration and Assembly Facility (SSAIAF)), and A&R Laboratory Management. The requirements tracking, integration analysis, technical management, and liaison for robotics comes from the Flight Robotic Systems Branch.

WP-2 Robotic Program Progress since the last ATAC report includes: (1) supporting the Canadian Space Agency (CSA) Special Purpose Dexterous Manipulator (SPDM) Preliminary Design Review (PDR), (2) incorporating Robotic Systems Integration Standards (RSIS) requirements into the WP-2 specifications and drawings through the Robotics Compatibility Requirements and RSIS Volume II Amended Documents, (3) releasing the Statement of Work to subcontractors, (4) developing and incorporating the WP-2 Robot Test and Verification Plan into applicable System/Element Verification Plans, (5) continuing the Kinematic Analysis and Hardware Testing Track Tasks which have already contributed to improving robotics designs, and (6) revising the WP-2 A&R Plan to reflect changes in direction since the program PDR.

Current Robotic Compatibility Program content includes: (1) baselining of RSIS for 75 6B Avionics Box ORUs and 6 Thermal Control Systems Small Fluid Box ORUs, (2) designing the passive radiator doors to be robot compatible, (3) providing robot stabilization points where necessary, (4) modifying WP-2 structures to accommodate robot compatible ORUs from other work packages (i.e., the Work Package 4 Remote Power Controller Mechanism) including hinged radiators and stabilization points, and (5) developing EVA ORU handling tools which interface with the RSIS interfaces (SPAR H Handle, SPAR Micro, and Microconical tools).

There has been little change in the status of either the Integrated Systems Executive (ISE) Caution and Warning synthesis software capability, or the Data Management System (DMS) Fault Detection Isolation and Recovery (FDIR) prototype projects. As discussed in the last report, early prototypes of the ISE Caution and Warning synthesis function demonstrated how a set covering approach could be used to diagnose systemic fault propagation and help synthesize numerous systems alarms caused by one fault into a message identifying the root cause. The DMS FDIR prototype has been completed and the results documented. Included are some lessons learned, related to the way in which knowledge based systems should be organized to comply with real time performance requirements.

The System Management Team (SMT) recommendations have added back some degree of autonomous capabilities to on board avionics. The SMT proposes approaches dealing with different fault classes, dealing with failed sensors, and shedding loads in a hierarchical fashion with degraded power system capabilities through the Avionics System Management Design Document. WP-2 has incorporated their requirements and has conducted a detailed design review to check the Flight Subsystem Software Requirements for compliance with these requirements.

A requirement for the Crew Health Care System (CHeCS) medical decision support system has been baselined as a part of JSC 31013, Revision C. Minimal impact is anticipated for incorporating the medical decision support system if the Commercial Off-The-Shelf software is integrated on a "medical equipment controller." There are several existing/tested knowledge bases available which will be evaluated in the selection process. Potential benefits of incorporating CHeCS into the SSFP include the first Artificial Intelligence (AI) Advanced Automation application to be incorporated on board the Space Station and the availability of standardized evaluations for the medical community which will reduce the need for on-board and ground based physicians.

The JSC Automation and Robotics Division, assisted by McDonnell Douglas Aerospace, is outfitting the SSAIAF for real-time dynamic simulations of on-orbit robotic operations. Test system capabilities will be delivered in phases including an upgraded Shuttle Remote Manipulator System capability for Space Station flights 1-3, Space Station Remote Manipulator System capability for flights 4-6, and full Space Station capability for Post Man-Tended Capability

(MTC) activities. SSAIAF plans to support SSFP for the complete life cycle with engineering evaluations, crew familiarization, and real time mission support during assembly and maintenance operations.

The Canadian Space Agency Special Purpose Dexterous Manipulator Preliminary Design Review described a new design that differs from the WP-2 baseline. The new design will create a change in the operating philosophy which will increase operational timelines and may increase power requirements. The major operational impact of the new design is that the "Stand Alone" mode using the SPDM directly from the Mobile Remote Servicer Base System is no longer available for WP-2 ORUs. Another impact is that the new design, in effect, establishes a requirement for additional H-fixtures and targets for SPDM stabilization on the front three faces of the truss.

Work Package 4 A&R Progress

Automation activities within Work Package 4 are focused in two areas: automated operation of the electric power system and robotic interfaces for maintenance.

The automation of ground operations for the power system has been sponsored by the Space Station Level I Engineering Prototype Development. Work Package 4 has begun the development of an operations console for the entire electric power system, featuring health monitoring and diagnostic expert systems for all generation and distribution functions.

This initiative includes use of the Power Management and Distribution testbed, which provides an environment for experimenting with flight-like hardware and software systems together with the Engineering Support Center which provides telemetry processing and ground operations console positions. The participants in this integrated operations console development include operations engineers drawn from Work Package 4 (both NASA and contractor) and the Space Station Mission Operations Project Office, Work Package 4 testbed engineers, and the advanced EPS FDIR team from Marshall Space Flight Center.

To coordinate the design contributions of all of the participants, Work Package 4 began modeling the functional behavior of the entire power system to determine what activities were required for ground operations. We initiated procurements for model documentation and direct participation by Work Package 4's prime contractor. At this time, functional analysis has been completed for the energy storage systems and has resulted in design requirements for the battery system operator's console. Any further work supporting the operations console will be completed by the Work Package personnel without direct support from the prime contractor, due to funding cuts and program restructuring.

Since the last ATAC report, Work Package 4 has extended its TROUBLE failure detection and diagnosis system to include battery charge regulator failures, verified its BATTMAN battery monitoring expert system with battery test data, and refined the human interfaces for both these systems. Experimental versions of these console positions and their decision support expert systems will be demonstrated at the Johnson Space Flight Center's Control Center Complex testbed this spring to solicit endorsements and critiques from mission flight controllers.

Work Package 4's prime contractor is pursuing an automation design for the flight system that features automatic regulation of battery charging, battery temperature, beta gimbal position, and array voltage regulation. All of these systems require setpoints specified by ground control. In addition, all pertinent system parameters are subject to automatic operating limit violation detection and reporting. Since the last ATAC report, Work Package 4 has completed its Critical Design Review (CDR) and all of these automation features have been incorporated into the final production design.

The robotics effort of Work Package 4 has focused on compatibility between its ORUs and the robotic systems planned for SSF. The end-to-end maintenance activities led by Level II have begun to delineate robotics requirements for all pieces of maintenance equipment. Work Package 4 will support the delineation of these requirements.

The end-to-end maintenance task group has been focusing their efforts on small ORUs with adapters that will be carried on subcarriers. Unfortunately, several Work Package 4 ORUs are larger than these and have not yet been addressed. Possible new requirements for subcarriers and adapter plates may cause Work Package 4 to incur additional costs and weight.

The Work Package 4 CDR identified two major areas that should be refined concerning verifying the RSIS requirements and developing the Robotics Task Verification Plan. Work Package 4's

robotics interfaces are not consistent with the RSIS requirements. A RID has been accepted to work this issue for all Work Package 4 ORUs. RSIS requirements will also need to be updated due to recent results from robotic testing in the neutral buoyancy test facility at Oceaneering Space Systems. Although Level II and CSA have the prime responsibility for developing the Robotics Task Verification Plan, Work Package 4 has been closely involved with plan development, such as defining tasks, providing ORU parameters and supplying models.

Mission Operations Projects Office A&R Progress

The Control Center Complex (CCC) is the facility which supports ground monitoring and control of both the Space Station and Space Shuttle vehicles. A synergistic approach in control center development has been pursued in order to improve quality and operations efficiency, as well as to lower development and operations costs.

The CCC design includes a distributed architecture, which is largely driven by the need to provide for the incorporation of automation and robotics technology in support of operations. The CCC Advanced Technology Testbed has been established in order to ensure a migration path for the integration of technology into the CCC. This testbed provides an environment for the early investigation of new technology applications by the flight controller user community with minimal impact to ongoing work requirements. The CCC testbed provides technical support for demonstrations and evaluations, as well as AI prototyping efforts. Currently, this testbed is being used to support fault management models assessment activities, as well as the evaluation of candidate baseline expert system shell Commercial Off-The-Shelf (COTS) products to be selected for future use throughout the CCC.

CCC development is achieved by providing a series of incremental deliveries and releases for early user feedback and then iteration on those capabilities in a short turnaround. The first CCC operational release was delivered in December 1992, which provided an early COTS platform to demonstrate a dual telemetry stream capability in a distributed environment using tools already available commercially or within NASA. Also included in this release were several Space Shuttle advanced monitoring and diagnosis programs, which demonstrated the CCC architecture's capability to support the incorporation of advanced automation.

The Fault Detection and Management (FDM) subsystem provides software to support the detection and diagnosis of faults for both the Space Station and Space Shuttle vehicles. It uses the strengths of the distributed architecture by providing a modular design which supports the incorporation of new technologies at minimal cost and operational impact. Within FDM, the Extended Realtime FEAT (ERF) project provides a real time fault analysis capability by using heuristics, advanced algorithms, fuzzy logic, and real time data to emulate mission controller interactions with FEAT. Knowledge based systems from the Real-Time Data System (RTDS) project are being rehosted to the CCC platform and used for Space Shuttle fault detection and analysis. Level I Engineering Prototype Development models are being assessed for use as potential space station fault detection and analysis applications within FDM as well. Software "hooks" are being designed into FDM to provide the capability to integrate these technologies into the system, as well as to provide a growth path toward the use of future technologies.

The Mission Operations Directorate (MOD) Models Assessment Team (MAT) evaluation of the SSFP Level I EPD Thermal Control System Automation Project (TCSAP) was completed in January 1993. Hands-on evaluations by flight controller users and facility development personnel were achieved in the CCC Advanced Technology Testbed. Results from the MAT evaluation of TCSAP were extremely positive, and flight controllers unanimously favored its incorporation as part of their operational capability in the CCC. Per the MAT recommendation, work to integrate TCSAP with the CCC FDM and ERF projects has already begun. As part of this early integration effort, a prototype interface between TCSAP and ERF is being developed, which will be tested and evaluated in the CCC testbed by August 1993.

A similar evaluation of Level I EPD fault management models for the SSFP Electrical Power System (EPS) began in March 1993. It is anticipated that future models will be evaluated (tentatively) every six months, with the evaluation of the Level I EPD model for the SSFP Environmental Control and Life Support System (ECLSS) currently scheduled to begin in August 1993.

In January 1993, the MOD Control Center Systems Division proposed several operations initiatives to the Office of Advanced Concepts and Technology (OACT) for the purpose of leveraging technology in support of CCC automation. Technology tasks proposed included advanced fault management capabilities

for the SSFP Data Management System and Propulsion System, advanced reasoning technology integration, and multi program technology enhancements. Project teams for these proposed efforts have been established between MOD and technologists at Ames Research Center, the Jet Propulsion Laboratory, and Johnson Space Center. Resulting technology applications, if funded, will be evaluated in the CCC Advanced Technology Testbed for migration to the operational CCC system.

Payload Operations Project Office A&R Progress

The automation activity within the Mission Operations Laboratory for the Payload Operations Projects Office is driven by the needs of operators to integrate, plan, monitor, command, and control Space Station payload activities. These activities are directed to the design and development of the Payload Operations Integration Center, the Work Package 1 Engineering Support Center, and the Space Station United States Operations Center. This development focuses on a generic core system that uses distributed computing, integrated system monitoring and control, standardized user interfaces, centralized database management and an open, flexible system environment. Since this core system is generic in nature, it provides multi-project support, realizing extensive savings across the agency in executing payload operations.

Since the last report, many design and prototype activities have progressed. The Enhanced Huntsville Operations Support Center System (EHS) Top Level Design Review was conducted. This review was an interim milestone to the Critical Design Review. Several prototypes have been completed which supported major subsystems of the EHS. For the Data Acquisition and Distribution System, network prototyping has been completed, addressing typical workstation data ingest capability and network reliability using the TCP/IP multicast protocol. Several commercial Relational Database Management System (RDBMS) products were analyzed for compatibility with the EHS telemetry and command database requirements, as well as with payload operations management requirements. Performance analysis was also done for each RDBMS product on two different hardware platforms. A commercial graphical user interface (GUI) development tool was analyzed for its ability to generate GUIs which could be driven efficiently by workstation-class computers. Finally, a prototype tool for COTS-based monitoring and control of distributed computing systems is being evaluated. This prototype will demonstrate management of several different vendor workstations using the Simple Network Management Protocol and the Management Information Base I & II standards. To date, the results of the evaluations of these prototypes have validated the design concepts which are being employed in the development of the EHS.

Space Station Ground Processing A&R Progress

KSC is currently performing a study to determine potential Space Station ground processing tasks that could benefit from the application of advanced technology. Space Station Freedom managers have been interviewed and an initial list of specific processing tasks that might benefit from advanced technology has been compiled. An initial review of technologies to apply to these tasks has begun and will continue during the next few months.

In addition to this study, the KSC Space Station Project Office hosted the Advanced Technology Advisory Committee (ATAC) on March 16-18, 1993. At the request of the ATAC, a discussion was held on the second day of the meeting that focused on the potential application of automation and robotics to KSC Space Station ground processing tasks. This discussion began with KSC providing a description of the Space Station processing job. This description included an overview of the current ground processing flows as well as an explanation of KSC ground support equipment and facilities. It was followed by a KSC presentation on the status of the advanced technology ground processing applications study. KSC also presented its current automation efforts in support of the Space Shuttle. At the conclusion of the meeting the ATAC was given a demonstration of Space Station ground processing Computer-Aided Design activities, conducted by McDonnell Douglas.

Appendix B

ATAC Recommendations for the SSF Redesign Team

A Redesign Team was appointed on March 9, 1993 by the NASA Administrator to provide a redesign of the Space Station Freedom. The President directed NASA to create an independent senior-level Panel to assess the goals and redesign options developed by the Redesign Team. The Panel was instructed to provide a final report of its findings to the Vice President by June 1, 1993.

Following are the Recommendations which ATAC provided to the SSF Redesign Team on April 1, 1993.

Automation and Robotics technology has significant potential benefits for the Redesigned Space Station Freedom (SSF). These benefits are in three areas important to the success of SSF:

- Reducing Life Cycle Costs.
- Enhancing Scientific Productivity.
- Reducing Crew EVA/IVA Requirements.

Recommendation to Reduce SSF Life Cycle Costs

1. ATAC recommends that the SSF Revised Program continue the implementation and utilization of advanced automation technology in SSF Ground Based Operations.

Recommendation Rationale:

Automation technology can greatly reduce life cycle costs associated with SSF ground-based operations. Major payoffs of advanced automation technology are amplification of human capabilities, performance, and realtime decision making; significantly improved planning and scheduling for complex operations; and significantly improved systems fault management and recovery planning. Initial implementation efforts of automation technology have significantly increased scheduling efficiency of STS flow processing at KSC and has significantly enhanced STS flight control capabilities at the JSC Mission Control Center (MCC).

An advanced automation technology testbed has been established at JSC to evaluate and validate technology transfer of advanced automation into SSF ground-based operations. Continued implementation and utilization of advanced automation for SSF will reduce the number of operations personnel required for SSF flow processing at KSC, required for the Control Center Complex (CCC) at JSC, and required for the SSF Payload Operations Integration Center (POIC) at MSFC. Automated ground-based operations will serve effectively as a basis for future migration of automation technologies on board SSF.

Recommendation to Enhance SSF Science Productivity

2. ATAC recommends that the SSF Revised Program provide the on-board data management capabilities to address the payload requirements of high volume science data and interactive remote operation.

Recommendation Rationale:

Current design for the SSF payload data interfaces was copied from the SSF core system. However, the payload data requirements are quite different:
Core Design versus Payload Requirements

• Distributed realtime communication and control vs. minimum on-board interconnectivity.

• Low data rates vs. high volume data uplink and downlink.

• Batch file processing vs. near realtime remote telescience.

• Customized interfaces vs. commercial industry standards.

This mismatch of core design and payload requirements has resulted in insufficient science data downlink and uplink capability, insufficient remote configuration capability, and high cost unique interfaces. Specific issues include: video compression, lack of fault tolerance of the payload data processor (SDP-7), health and status data, control of downlink resource allocations, insufficient data and video uplink capability, use of a manual patch panel for data communications, use of the IEEE 802.4 data bus, an internal video system, limited on-board camera capabilities, video time base corrector, payload object database, and payload interface requirements document.

Also, any deviation from the current open architecture guidelines may constrain the ability to evolve in the future with system upgrades. These issues appear to have resulted partially due to the fact that the PDS has not been considered one of the SSF "subsystems" and therefore has not been formally part of the CDR process. It is vitally important that the SSF payload data system have the capabilities and flexibility required to support scientific payloads.

Recommendation to Reduce Crew EVA/IVA Requirements

3. ATAC recommends that the SSF Revised Program initiate implementation and utilization of ground-controlled telerobotics for assembly, operations, and maintenance to reduce crew EVA/IVA time requirements.

Recommendation Rationale:

A large portion (48%) of the SSF ORUs are being designed to accommodate telerobotic maintenance. Recent cost reduction redesigns of the Canadian Mobile Servicing System (Space Station Remote Manipulator-SSRMS & Special Purpose Dextrous Manipulator-SPDM) indicate that the IVA timelines for on-board telerobotic operations could be considerably increased. This increase of IVA to support on-board telerobotic operations could impact the ability to complete on-board payload and science operations unless the on-board telerobotics crew workload is reduced.

Tests have been completed that indicate that the up-link/down-link telemetry delays in telerobotic signals can be accommodated through the implementation of qualified and proven telerobotic technologies. Therefore, more emphasis should be placed on developing the capability of ground teleoperation of the SSRMS/SPDM. Also, implementation of ground control of telerobotics will provide a non-tended capability that could prove very useful throughout the Man-Tended Capability (MTC) SSF operational period and future long duration research. Hooks and scars for ground telerobotic operations need to be planned as soon as possible to minimize future cost impacts on SSF. SSFP needs to undertake a concerted effort to develop and implement a capability to operate the SSF robotic systems from the ground (Control Center Complex). An important part of this effort would be a demonstration of a flight-like architecture performing typical robotics tasks. OACT should be strongly included as a member of this development activity.

The technology for the Canadian Space Agency robots and for the NASA JSC ground controlled telerobotics console is available and is compatible to enable successful ground-controlled telerobotics operation on SSF. The Canadian Space Agency, JSC Mission Operations, the Astronaut Corps, and the SSF robotics architect concur that certain robotic operations should be performed from the ground to reduce crew EVA/IVA time requirements.

Appendix C

Strategic Development Within the Canadian Space Agency's Space Station Freedom Project Office

Strategic Development is tasked to provide support to Space Station Freedom (SSF) over its 30 year life. There are three basic components: Space Station Operations and Utilization, Industrial Development and Evolutionary MSS (EMSS)/Strategic Technologies in Automation and Robotics (STEAR). This discussion deals with EMSS/STEAR.

Give the 30 year scheduled life of SSF and the lead time for design launch, Canada anticipated a mid-life upgrade program to the Mobile Servicing System which would improve the components in the baseline plus add additional capability to respond to user needs. This would have to be done in a manner which effectively contained costs and maximized Canada's original investment in the space segment of MSS.

Figure 1 gives the basic model used to move technology into baseline MSS. For a future upgrade, Canada was required to ensure that a new set of basic and critical technologies were available to meet the new requirements.

The vehicle chosen to achieve this was the STEAR program. Begun in 1988, it is an eleven year $55 million program designed to deliver the new technology needed for the future EMSS program. It was designed to be industry led but with strong input from both research laboratories and universities. To ensure the growth of new and innovative technologies, the MSS prime contractor, SPAR, and its five principal subcontractors were excluded from participation. Furthermore, commercialization of technology was established as a key program element to encourage multiplication of the CSA investment. Figure 2 illustrates the potential direction of the technology flow.

The process was kicked off by assembling a group of robotics experts from industry, government, and universities. They went through a process of defining the ten most critical areas for robotics and ranking them in order of importance. These defined the topics for a series of research projects.

Each project consisted of two or three phases, the first of which was a detailed feasibility study. Each was completed, with four to six contractors entering Phase I. Progression to further phases was dependent on satisfactory performance of both the technical work and the identification of terrestrial applications. CSA would therefore have available not only a range of needed technologies, but multiple contractors for each.

The principal thrust of the research was a movement toward autonomous operations. This would reduce the workload on the man-in-the-loop, be it an astronaut or a ground controller. This would also lead to the capability to address increasingly complex tasks while responding to NASA's stringent safety requirements. Specific technologies included expert systems, health monitoring, trajectory planning, collision avoidance, autonomous operation, ground control, vision systems, and tactile and proximity sensing. The autonomous operation work was structured in a modular manner to permit integration of other activities (i.e., vision systems) and as

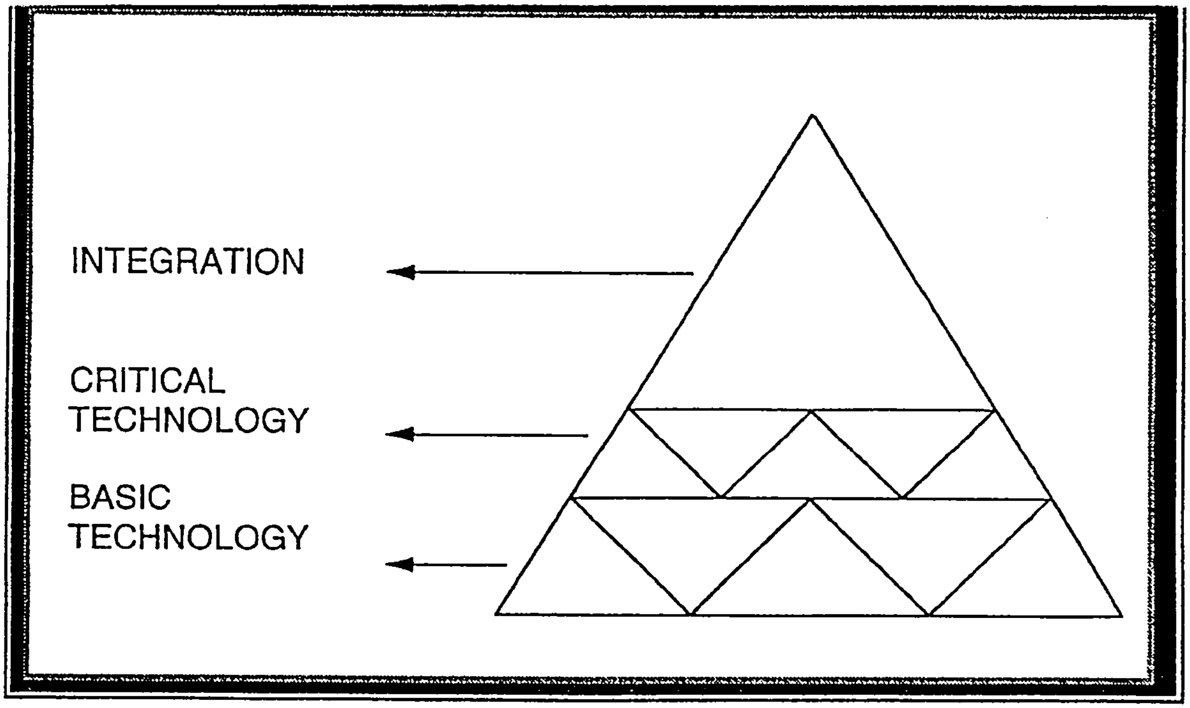

Figure 1. How the Technology Builds to the MSS Application.

well as respond to different control modes (i.e., teleoperation or semi-autonomous). This is illustrated in figure 3.

As stated earlier, there was not only an emphasis on the technology for space application, but also terrestrial application. There was a realization that results would be achieved far in advance of funding for the EMSS program. Consequently, to ensure that the companies survived and the technology development continued, terrestrial applications or commercialization were a requirement in each project. Figure 4 demonstrates how the technologies related to the space market can be applied to other markets.

As a further leverage to funds, CSA participates with provinces, development agencies, and research agencies in joint ventures. This activity not only increases the funding available to CSA projects, but also meets the political objective of establishing expertise in various regions of Canada. Staff in Strategic Development also work with contractors to identify funding sources in other government departments to support market studies or the development of the technology to their applications.

Success in the commercialization area has been achieved. One contractor is now working with the USAF on an automatic aircraft refueling system based on STEAR technology. Another has developed an automated truck routing system that is in commercial use. Optech has combined with a German company to market a laser terrain mapping system. A small Nova Scotia company has just released a miniature fiber optic rotary joint as a result of a robotic small wrist project.

Perhaps the greatest success of the STEAR project is the networking that occurs between the industrial partners and the ability of the program to draw technology out of research labs and universities into the market. This is illustrated by the project team for one of the autonomous operations contracts as shown in figure 5.

The STEAR program is just passing its half-way point. A recent external

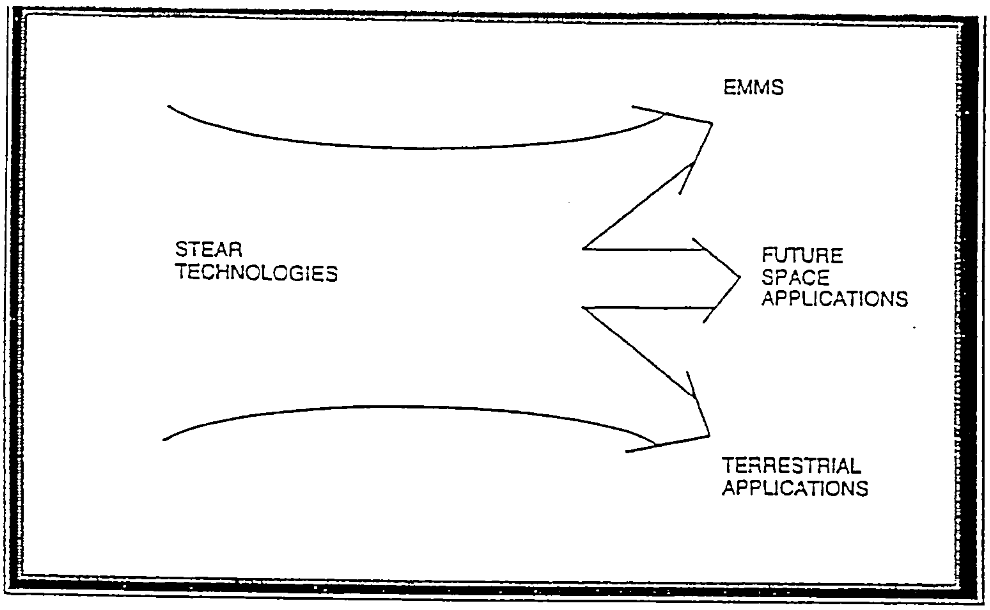

Figure 2. Potential Paths for STEAR Technology.

midterm evaluation found the program to be meeting its goals and objectives, with full support from both contractors and government. Over 60 companies and 20 universities are presently participating. CSA is ensuring a sound base of technology upon which to build the next generation MSS and is successfully transferring space technology into the commercial marketplace.

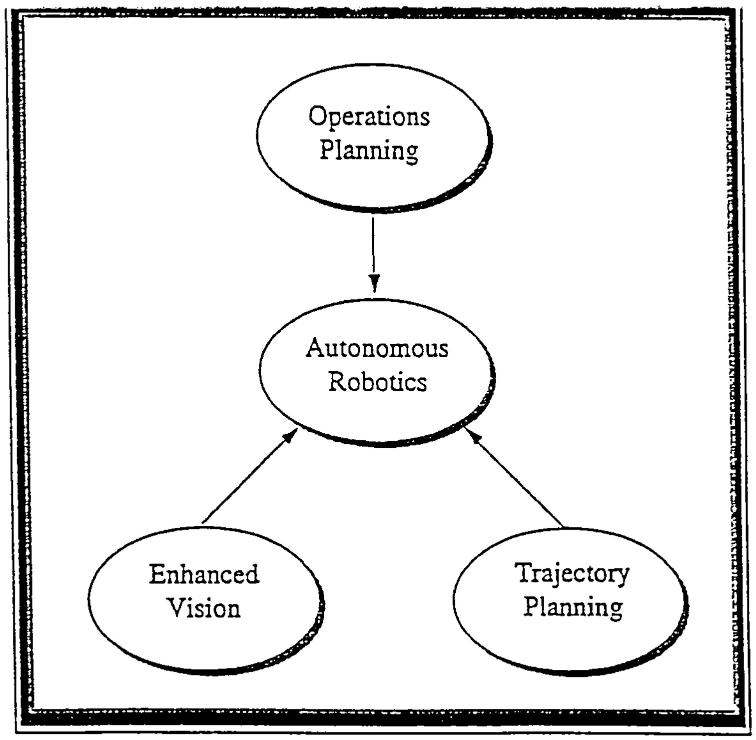

Figure 3. STEAR Projects Feed Into Other Projects.

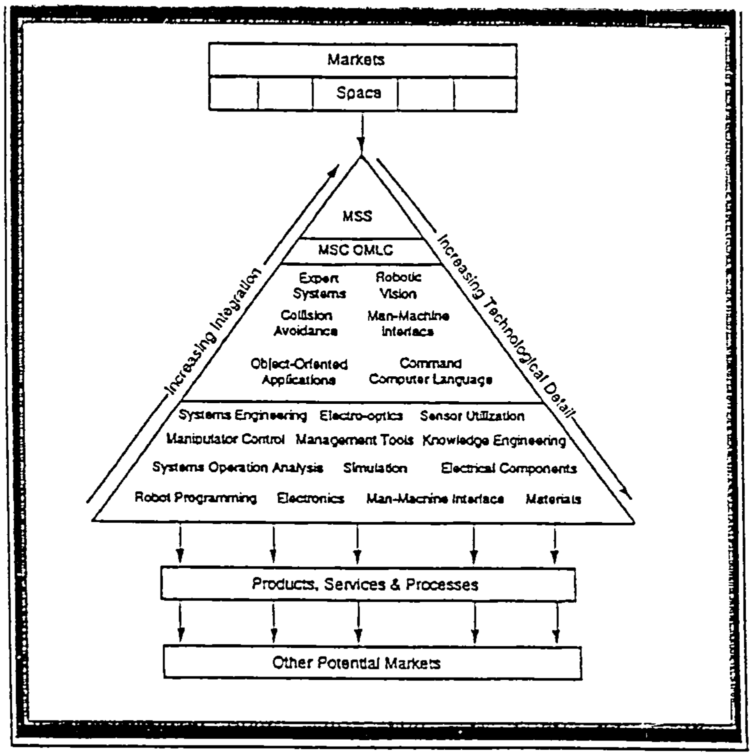

Figure 4. Model to Apply Space Technology to Terrestrial Applications.

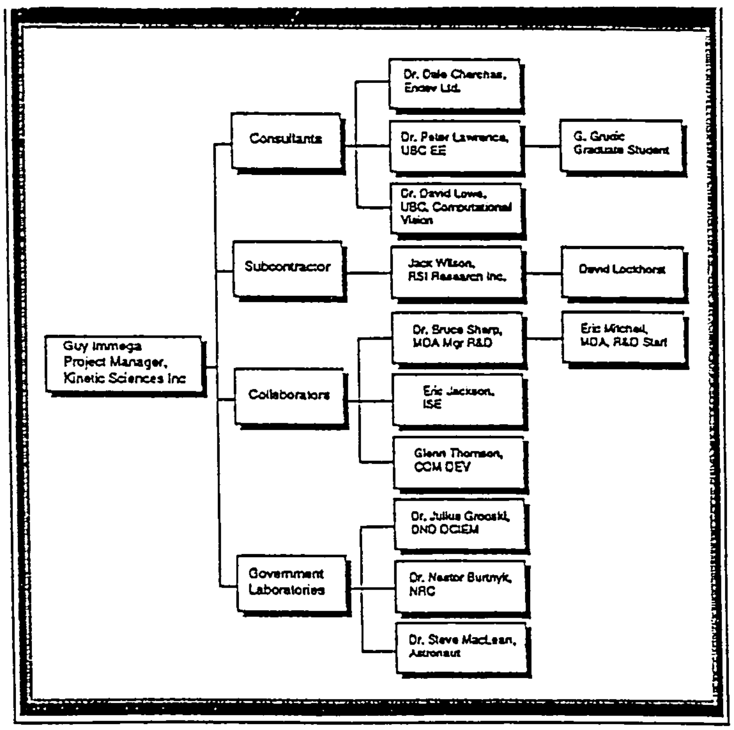

Figure 5. Sample STEAR Project Team.

Appendix D

Acronyms

A&R	Automation and Robotics
AC	Assembly Complete
ARC	Ames Research Center
ATAC	Advanced Technology Advisory Committee
AWP	Assembly Work platform
C&T	Communications and Tracking
CCC	Control Center Complex
CDR	Critical Design Review
CETA	Crew and Equipment Translation Aid
Code C	NASA HQ Code for the Office of Advanced Concepts Technology
Code D	NASA HQ Code for the Office of Space Systems Development
Code DE	NASA HQ Code D, Systems Development, Space Station Engineering
Code M	NASA HQ Code for the Office of Space Flight
Code S	NASA HQ Code for the Office of Space Science and Applications
CR	Change Request
CSA	Canadian Space Agency
CSP	Canadian Space Program
DARPA	Defense Advanced Research Projects Agency
DKC	Design Knowledge Capture
DMS	Data Management System
DTF-1	Development Test Flight (first FTS test flight)
DTLCC	Design to Life-Cycle Costs
ECLSS	Environmental Control Life-Support System
EMI	Electric-Magnetic Interference
EMST	External Maintenance Solutions Team
EPD	Engineering Prototype Development
EPS	Electrical Power System
ESA	European Space Agency
EVA	Extravehicular Crew Activity
EVR	Extravehicular Robot Activity
FDIR	Fault Detection, Isolation, and Recovery
FEL	First Element Launch
FSE	Flight Support Equipment
FTS	Flight Telerobotic Servicer
GN&C	Guidance, Navigation, and Control
GSFC	Goddard Space Flight Center
HOSC	Huntsville Operations Support Complex
IDR	Integrated Design Review
IROP	Integration Requirements on Payloads
IR&D	Inhouse Research and Development
ISE	Integrated Station Executive
IVA	Intravehicular Activity
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center

KBS	Knowledge-Based Systems
KSC	Kennedy Space Center
LaRC	Langley Research Center
LCC	Life-Cycle Cost
LeRC	Lewis Research Center
MCC	Mission Control Center
MSAD	HQ Microgravity Science and Applications Division
MSC	Mobile Servicing Center
MSFC	Marshall Space Flight Center
MTC	Man-Tended Capability
MUT	Mission Utilization Team
NASA	National Aeronautics and Space Administration
OACT	Office of Advanced Concepts Technology
OMS	Operations Management System
ORU	Operational Replacement Unit
OSSA	Office of Space Science and Applications
OSSD	Office of Space Systems Development
PDR	Preliminary Design Review
PDS	Payload Data System
PDRD	PDR Document
PI	Principal Investigator
PIT	Pre-Integrated Trusss
PMAD	Power Management and Distribution
PMC	Permanently Manned Capability
POIC	Payload Operations Integration Center
POP	Program Operating Plan
RSIS	Robotic Systems Integration Standards
RTDS	Real-Time Data System
SPAR	Spar Aerospace Limited
SSFPAH	Space Station Freedom Payload and Accommodations Handbook
SSSAAS	Space Station Science and Applications Advisory Subcommittee
SDP	Standard Data Processor
SDTM	Station Design Tradeoff Model
SPDM	Special Purpose Dexterous Manipulator
SSCC	Space Station Control Center
SSE	Software Support Environment
SSEIC	Space Station Engineering and Integration Contractor
SSF	Space Station Freedom
SSFP	Space Station Freedom Program
SSPF	Space Station Processing Facility
SSRMS	Space Station Remote Manipulator System
TCS	Thermal Control System
TEXSYS	Thermal Expert System
WETF	Weightless Environmental Test Facility
WP	Work Package

Appendix E

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In April 1985, as required by Public Law 98-371, the NASA Advanced Technology Advisory Committee (ATAC) reported to Congress the results of its studies on advanced automation and robotics technology for use on Space Station Freedom. This material was documented in the initial report (NASA Technical Memorandum 87566). A further requirement of the law was that ATAC follow NASA's progress in this area and report to Congress semiannually. This report is the sixteenth in a series of progress updates and covers the period between September 15, 1992 – March 16, 1993. The report describes the progress made by Levels I, II, and III of the Space Station Freedom in developing and applying advanced automation and robotics technology. Emphasis has been placed upon the Space Station Freedom Program responses to specific recommendations made in ATAC Progress Report 15; and includes a status review of Space Station Freedom Launch Processing facilities at Kennedy Space Center. Assessments are presented for these and other areas as they apply to the advancement of automation and robotics technology for Space Station Freedom.

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